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Knox

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(54) **HIGH ISOLATION SIGNAL ROUTING ASSEMBLY FOR FULL DUPLEX COMMUNICATION**

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Related U.S. Application Data

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(51) **Int. Cl.**
H04B 7/005 (2006.01)

(52) **U.S. Cl.** **370/278**; 385/16; 385/17

(58) **Field of Classification Search** 370/277, 370/278; 385/16, 17
See application file for complete search history.

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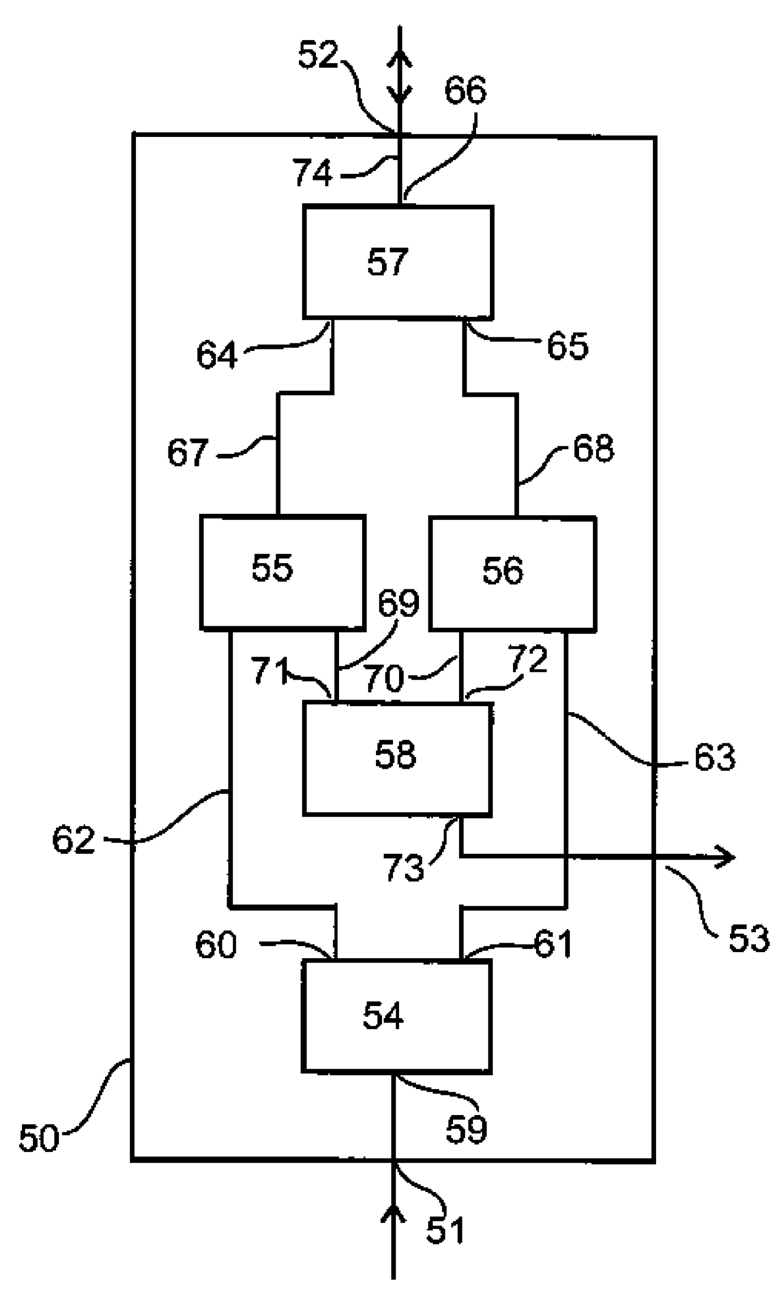
(74) *Attorney, Agent, or Firm* — Herbert E. Ruschmann

(57) **ABSTRACT**

A signal routing assembly accepts a first transmission signal at an input and outputs a substantial portion of the signal at a common port of the signal routing assembly. A second transmission signal is received at the common port and is routed through the signal routing assembly delivered to output of the signal routing assembly. Leakage signals from routing devices leaking the first transmission signal are terminated inside the signal routing assembly. Leakage signal from a divider/combiner are cancelled by reflect signal from at least one reflector device. A transmitter produces the first transmission signal and the signal routing assembly delivers this signal to the common port of the signal routing assembly. In full duplex operation, second transmission signals received at the common port are routed to the output to be applied to a receiver.

45 Claims, 16 Drawing Sheets



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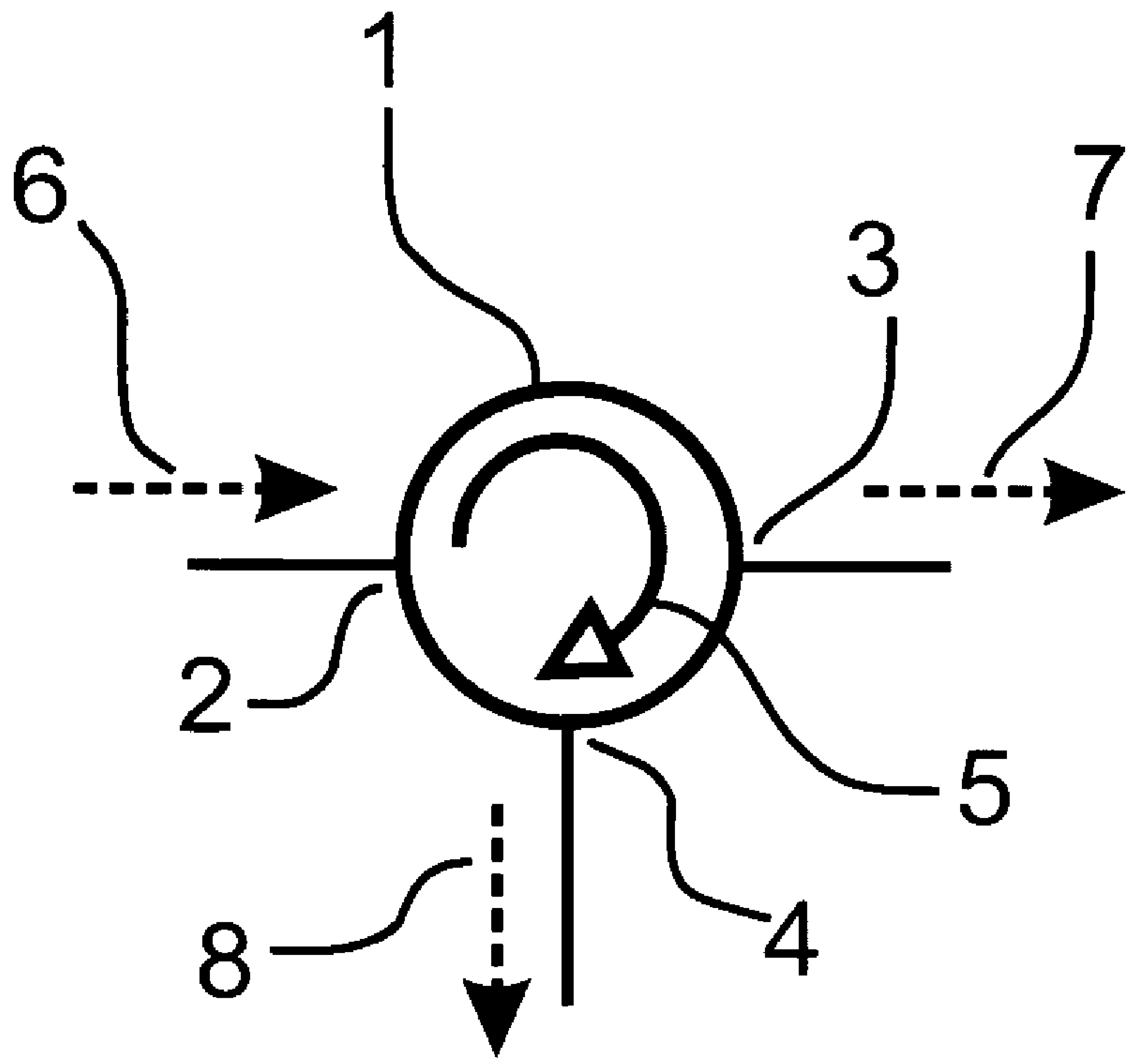
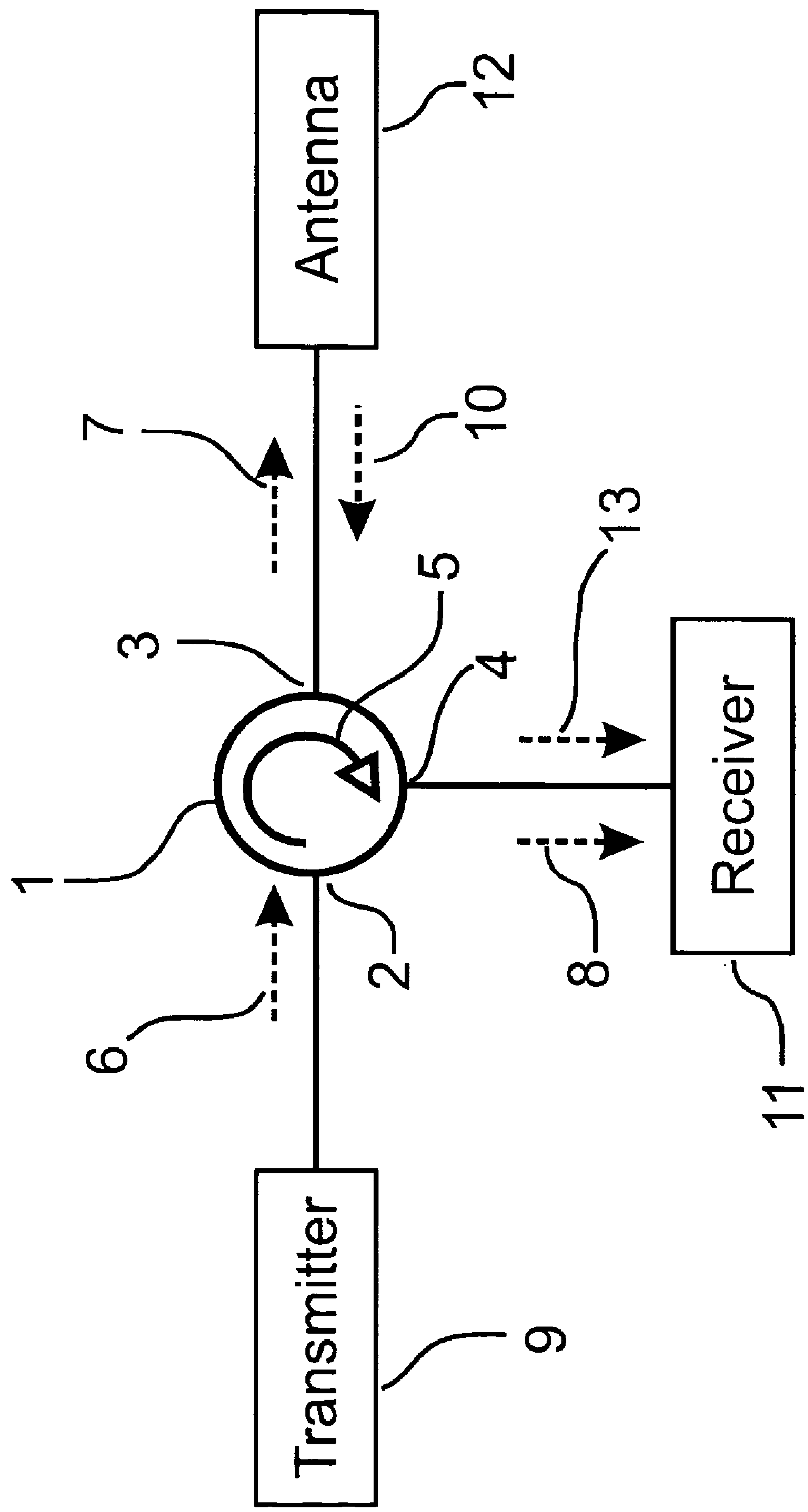


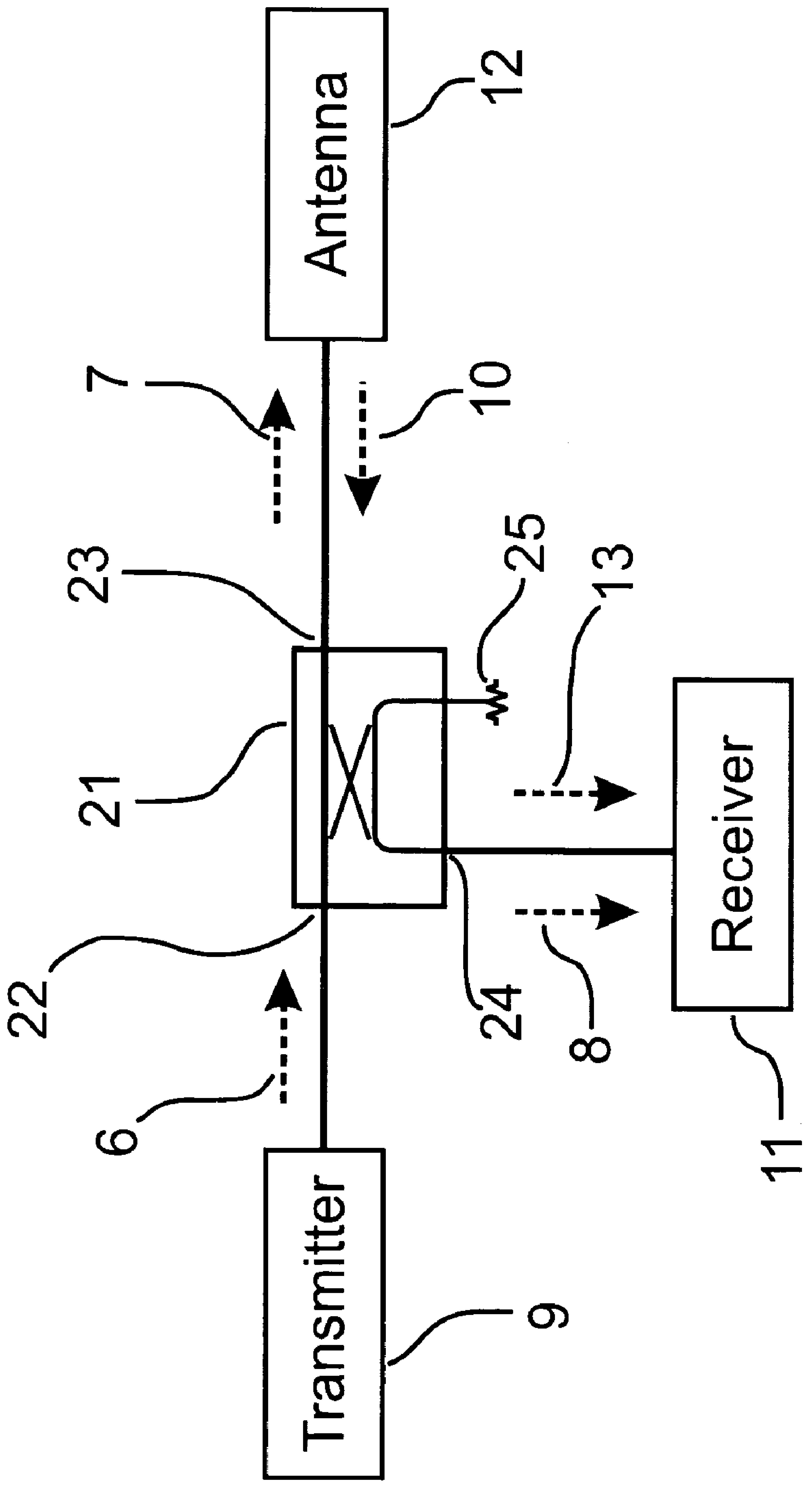
PRIOR ART

FIG. 1



PRIOR ART

FIG. 2



PRIOR ART

FIG. 3

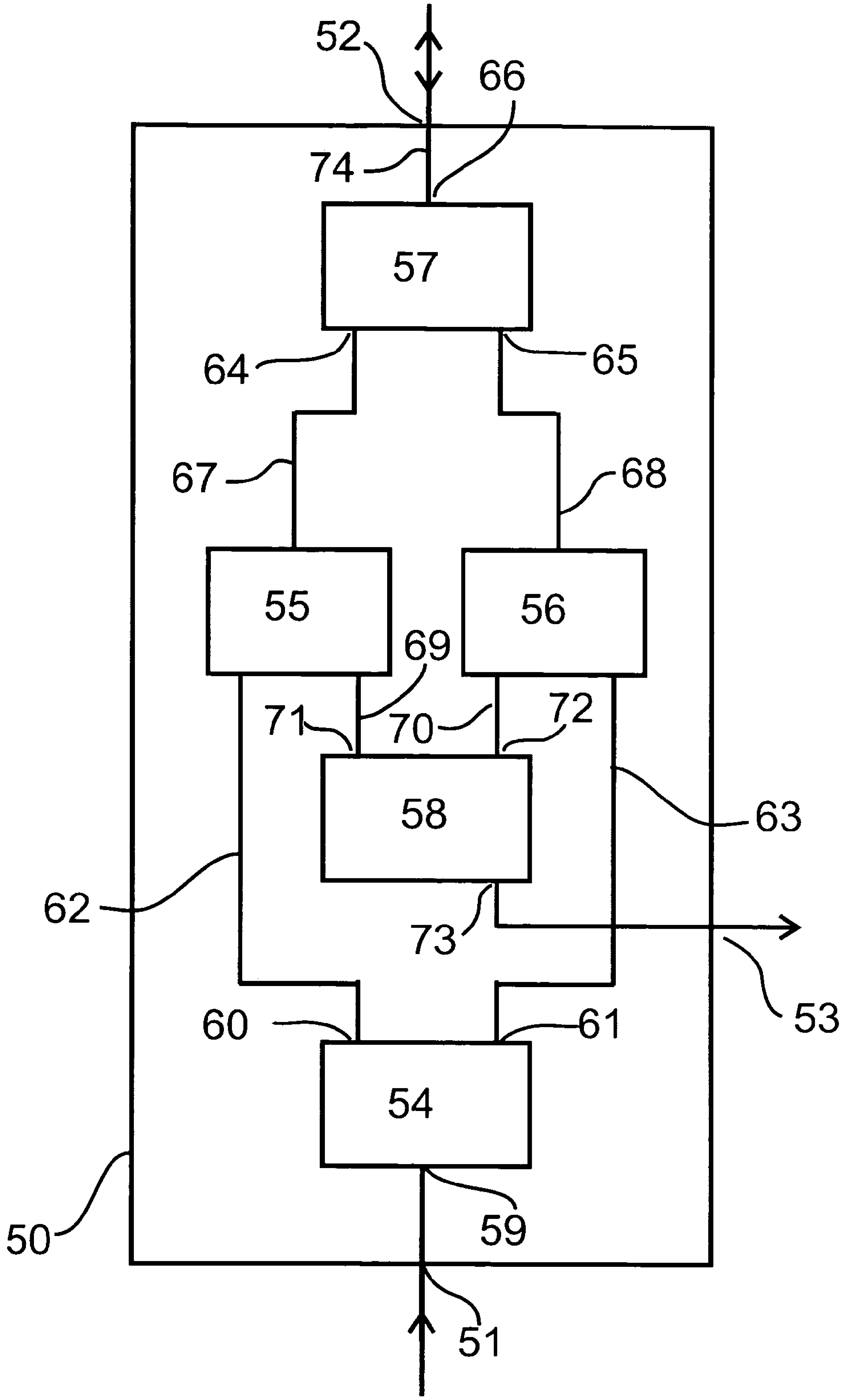

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FIG.4

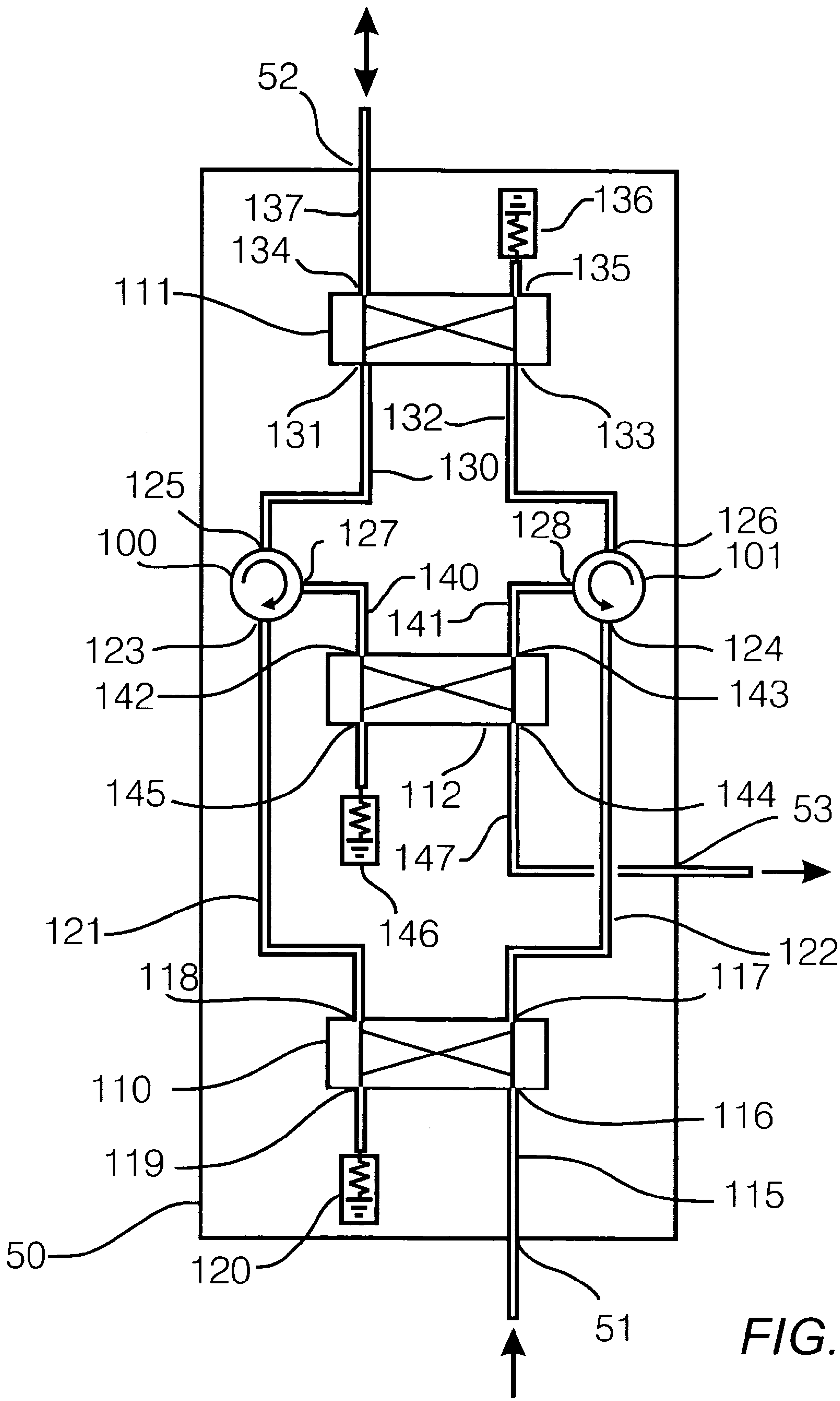
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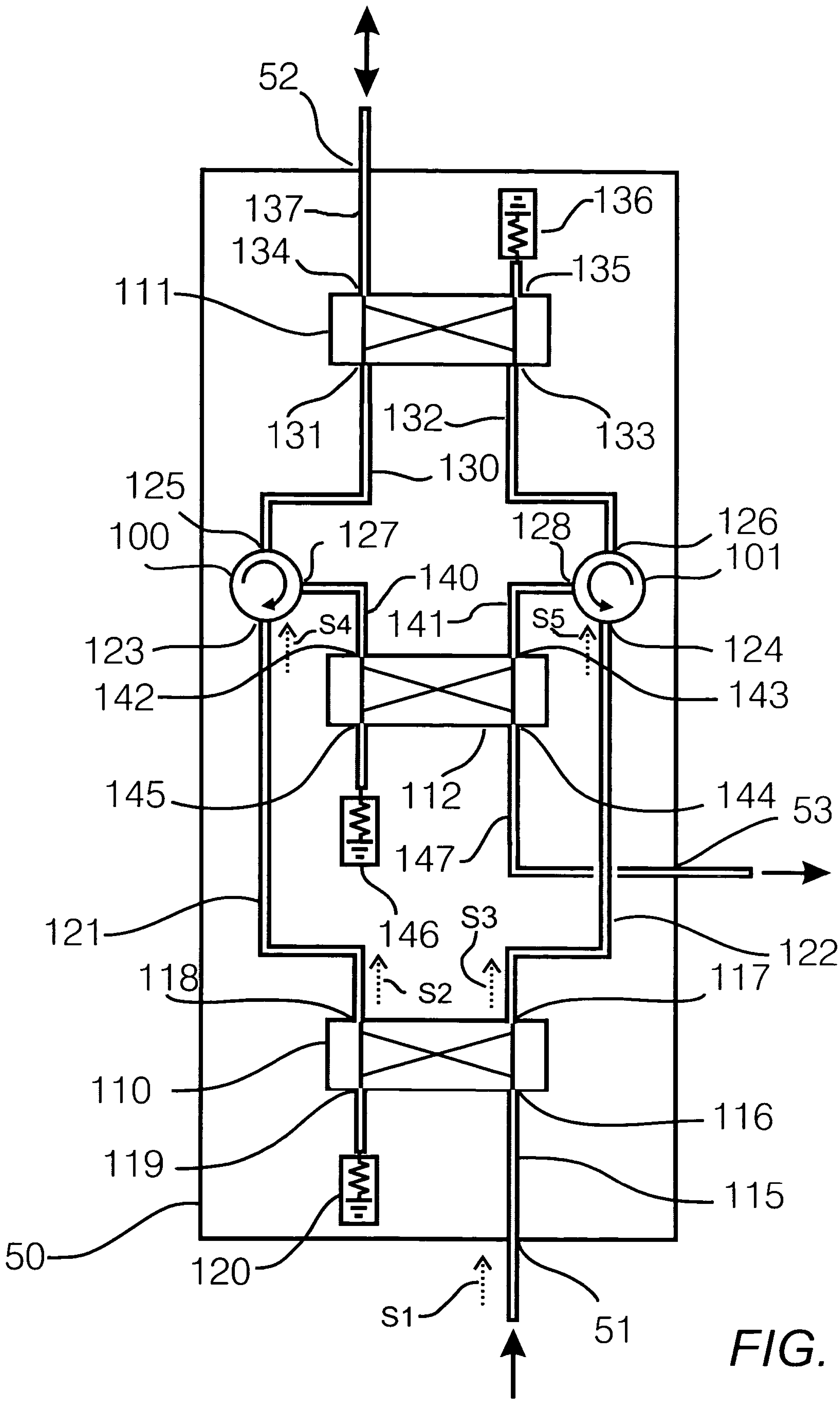
FIG. 5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S1
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FIG. 6

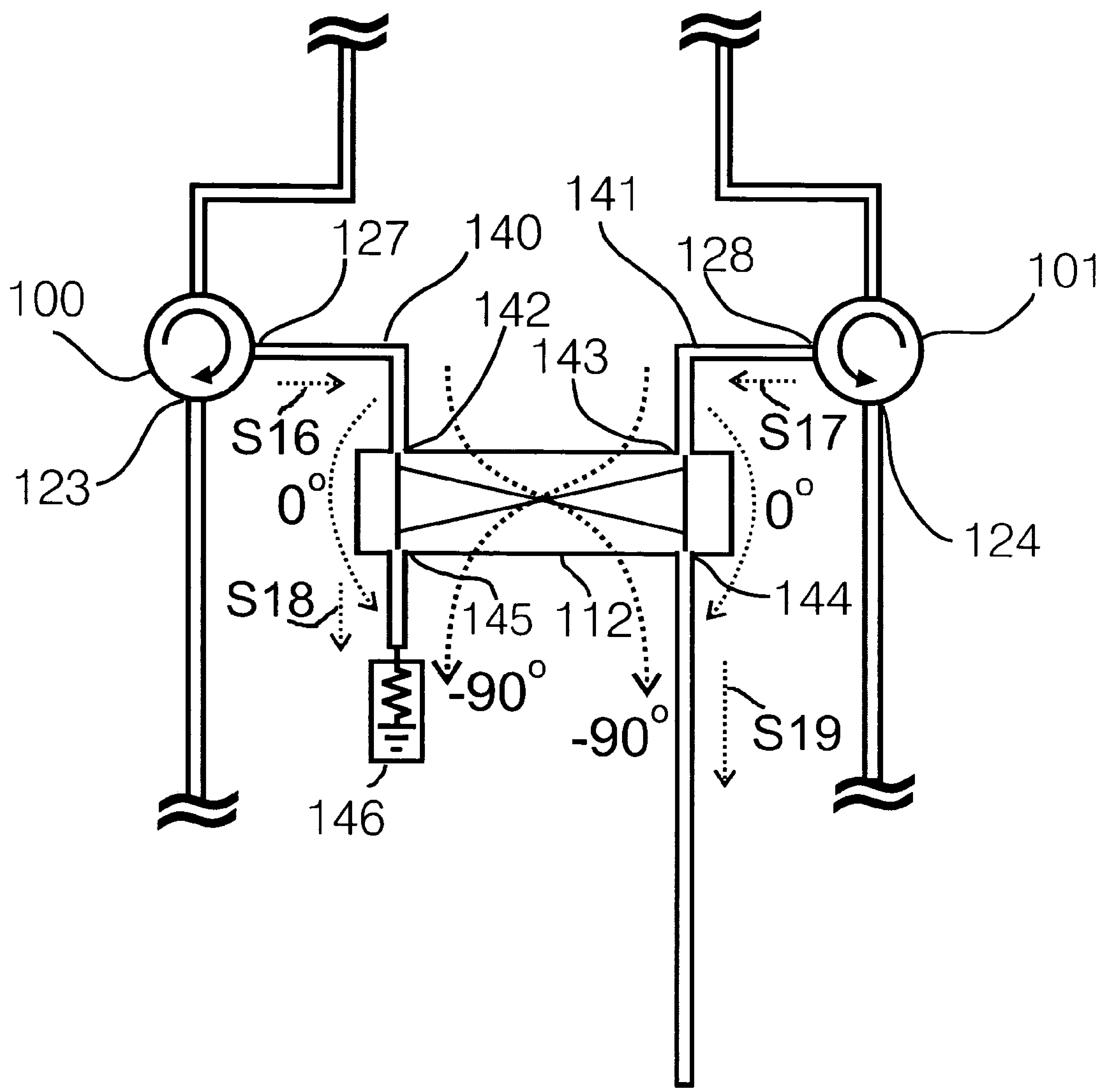
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FIG. 7

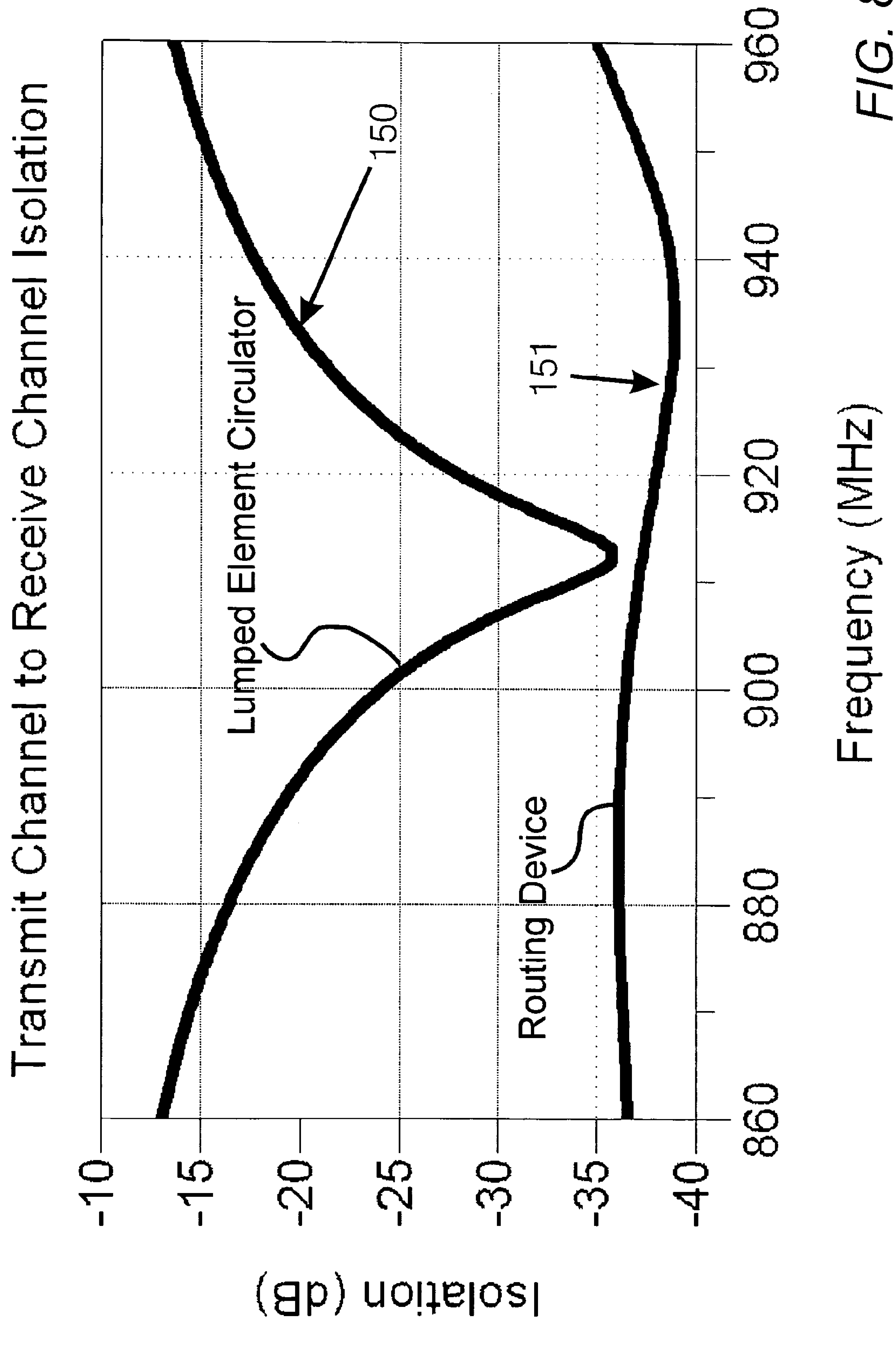
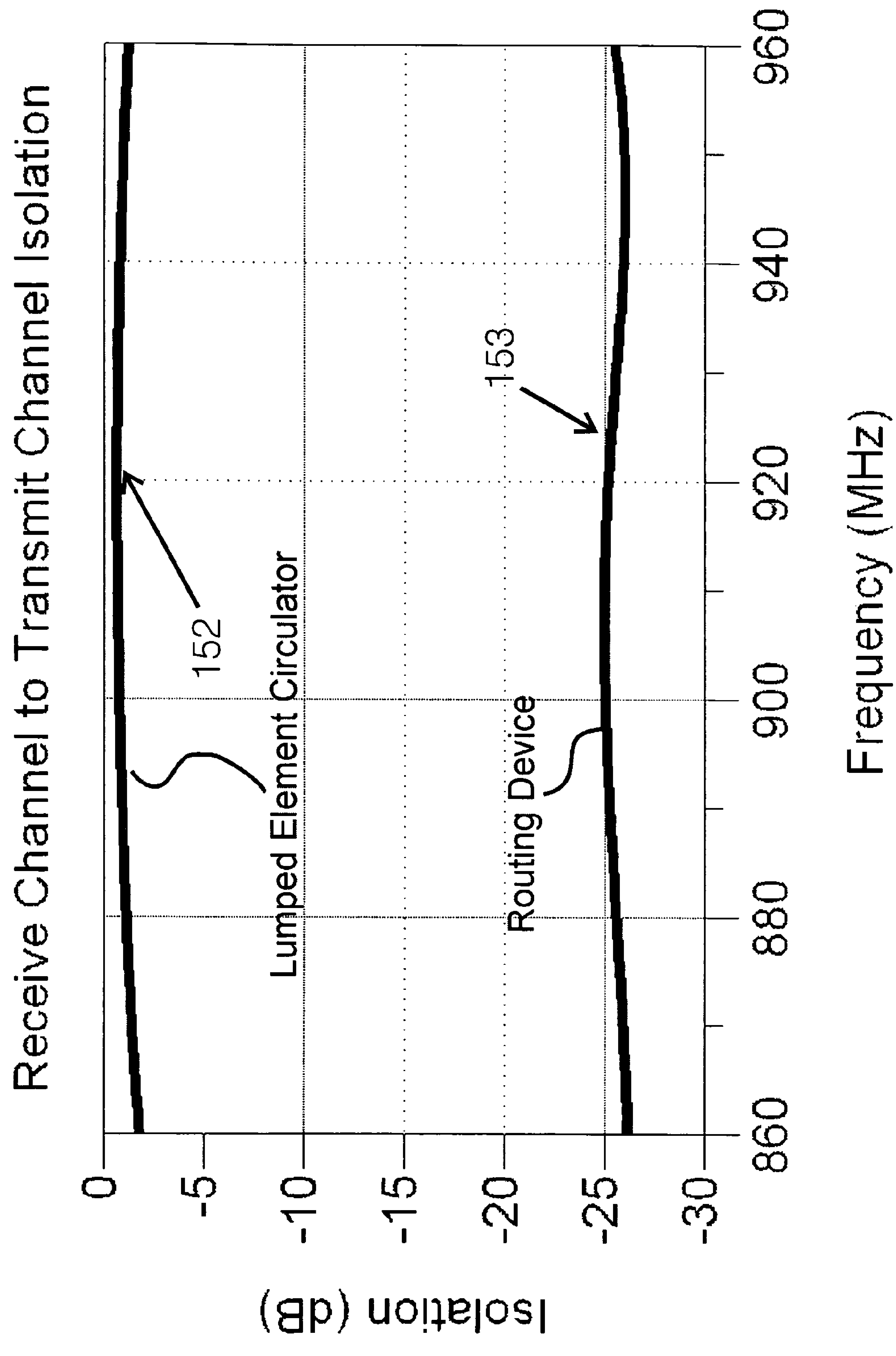

Transmit Channel to Receive Channel Isolation
Isolation (dB)
-10
-15
-20
-25
-30
-35
-40
860
880
900
920
940
960
Frequency (MHz)
Lumped Element Circulator
Routing Device
150
151

FIG. 8


Receive Channel to Transmit Channel Isolation
Isolation (dB)
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-10
-15
-20
-25
-30
860
880
900
920
940
960
Frequency (MHz)
152
153
Lumped Element Circulator
Routing Device

FIG. 9

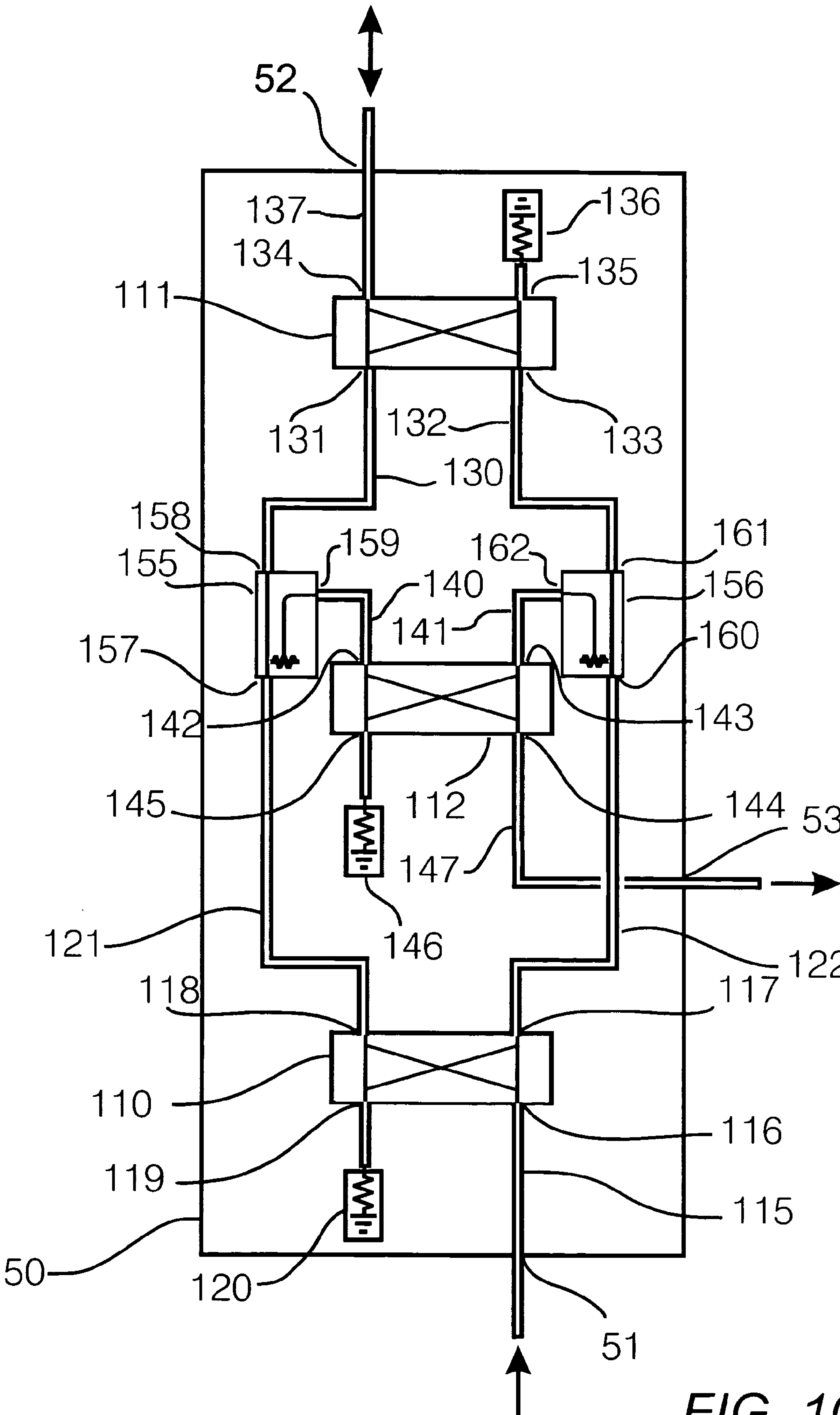
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FIG. 10

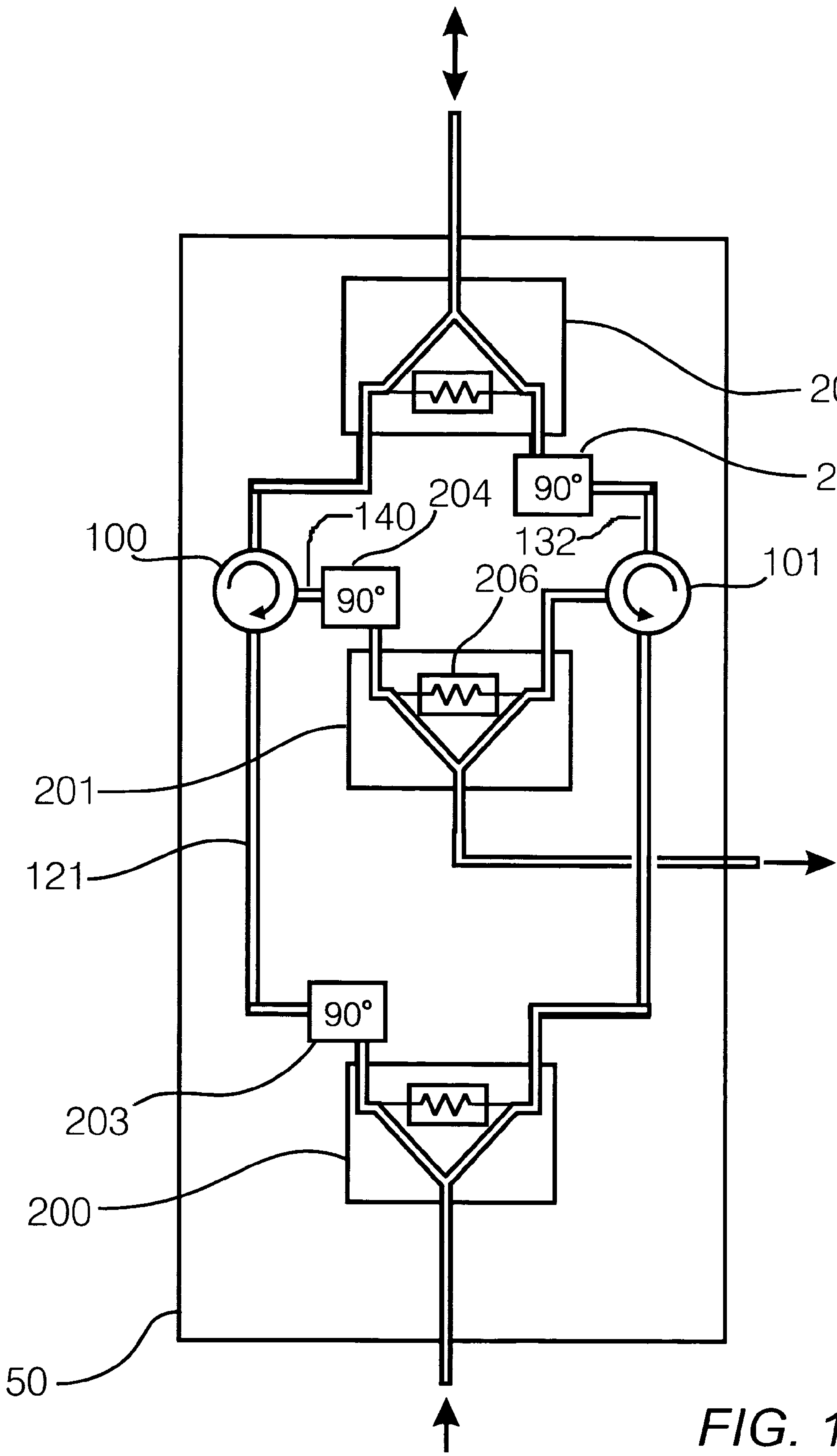

FIG. 11

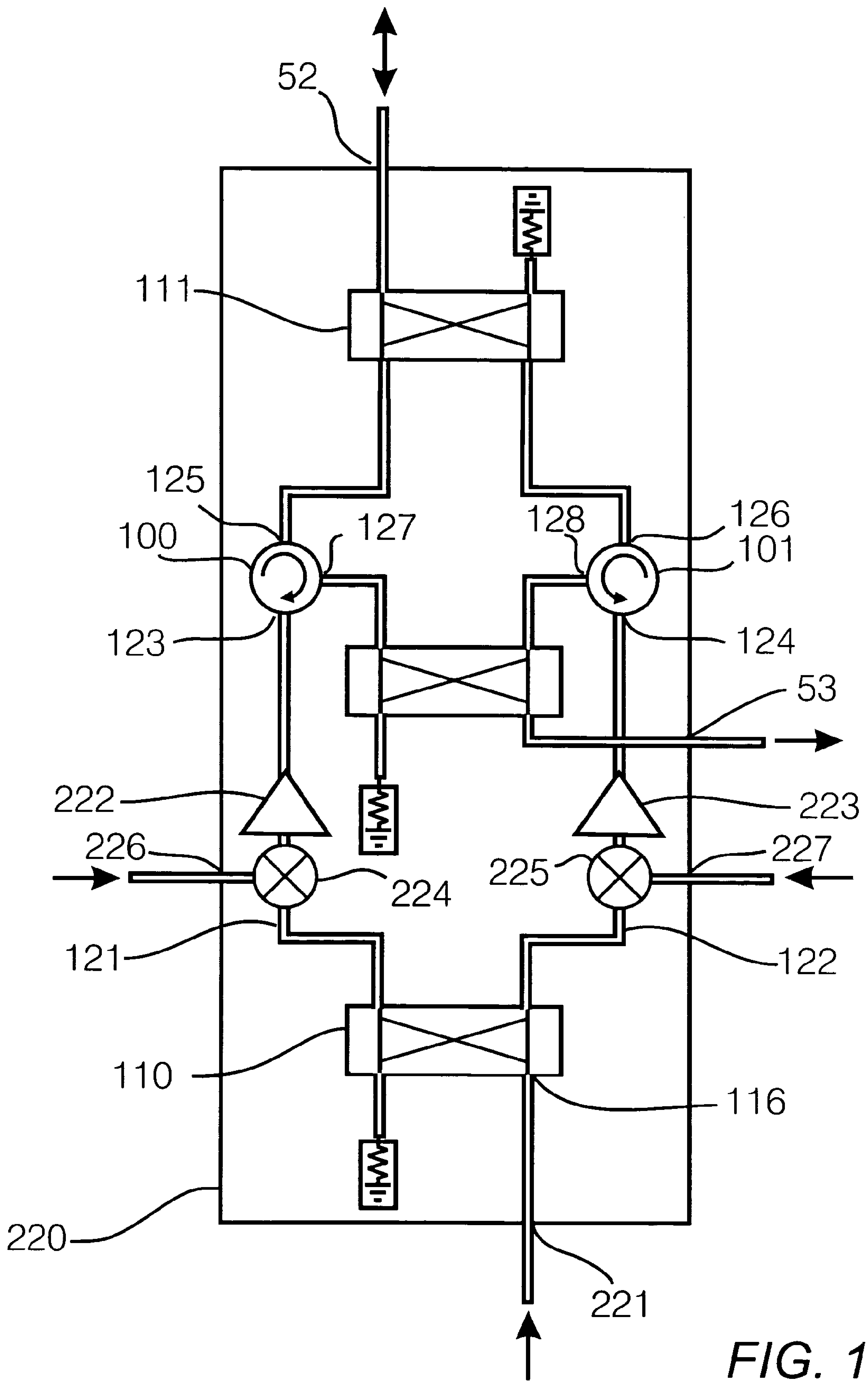
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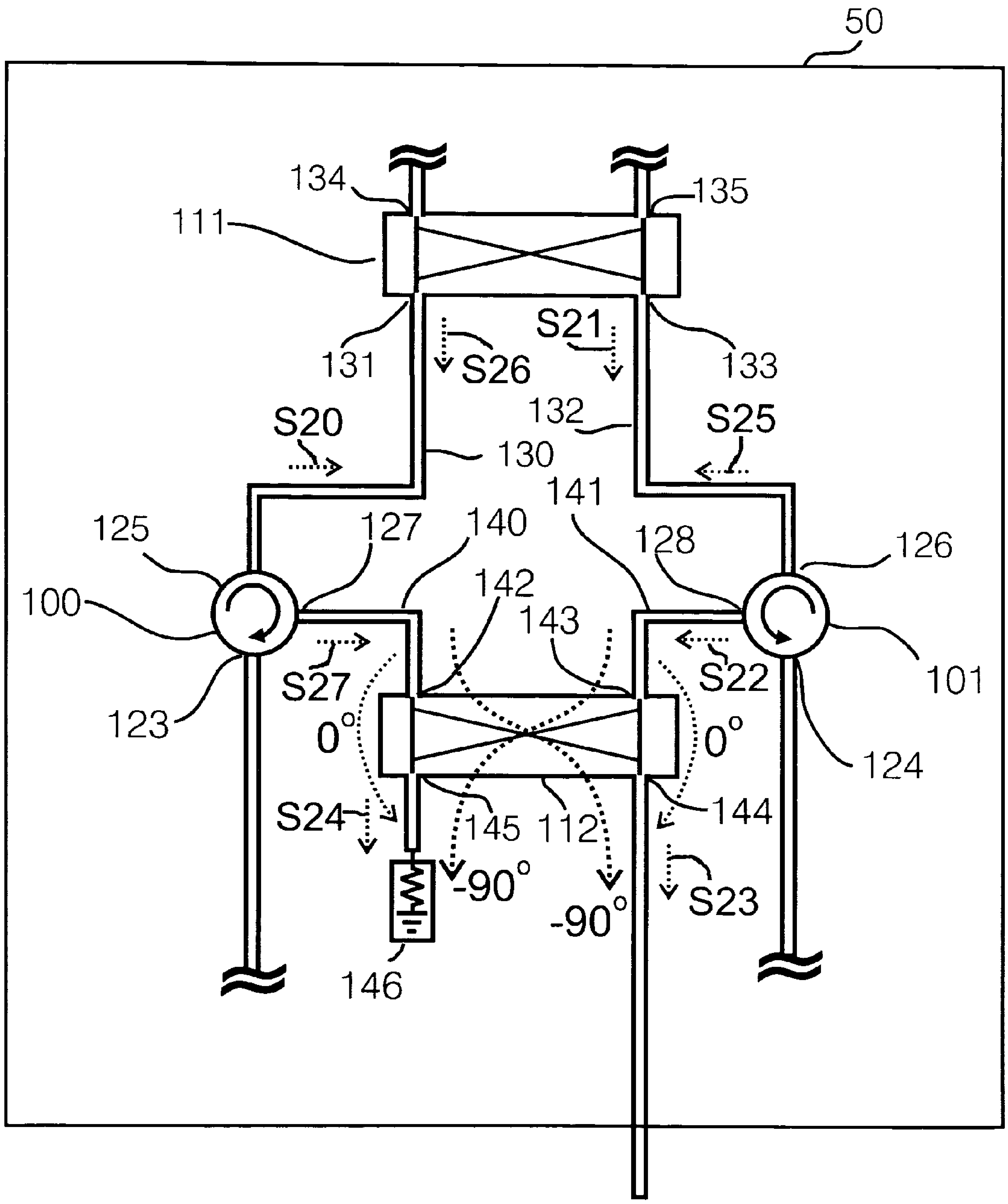
FIG. 12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S27
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S23
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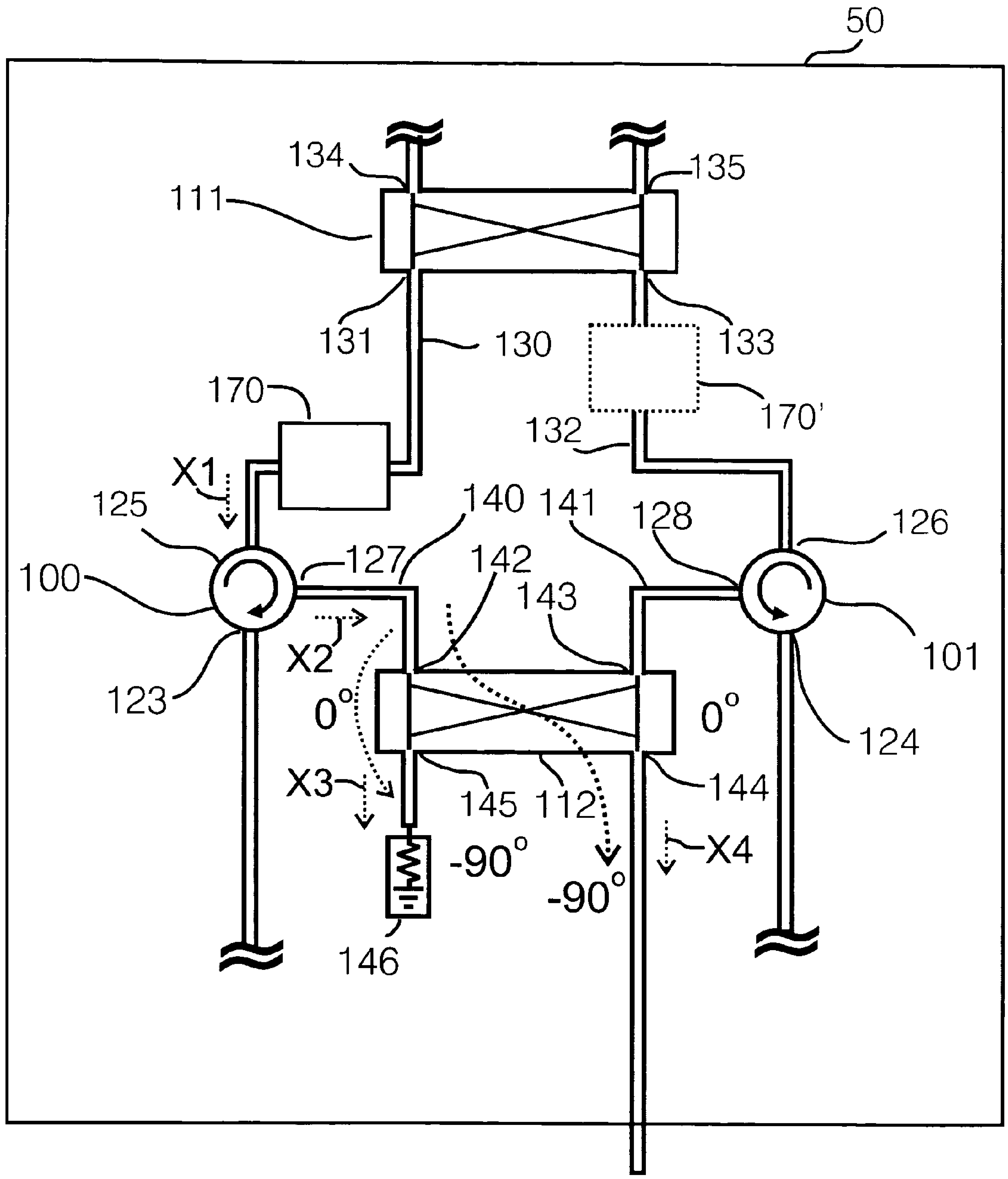
FIG. 13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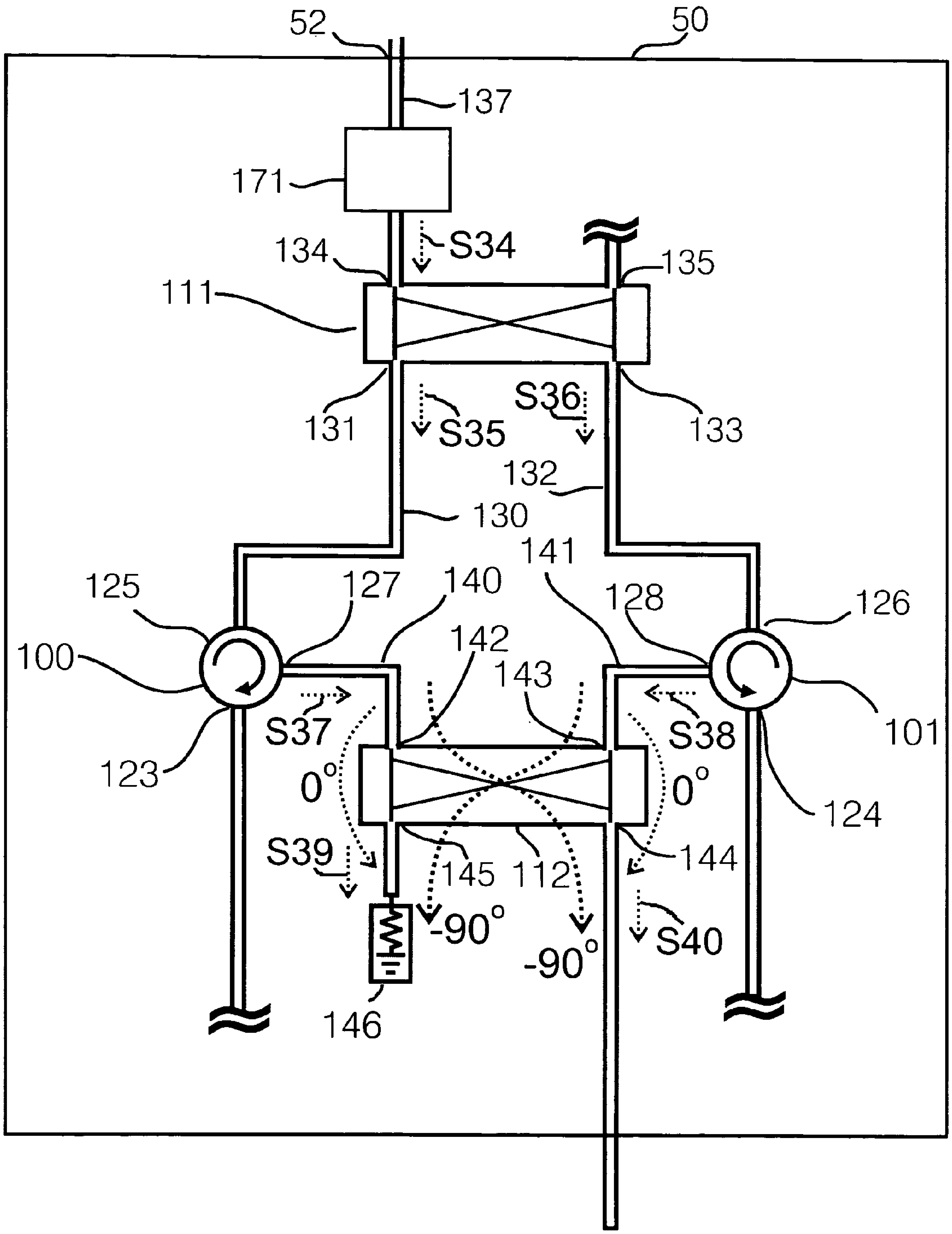
X4
146

FIG. 14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S40
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FIG. 15

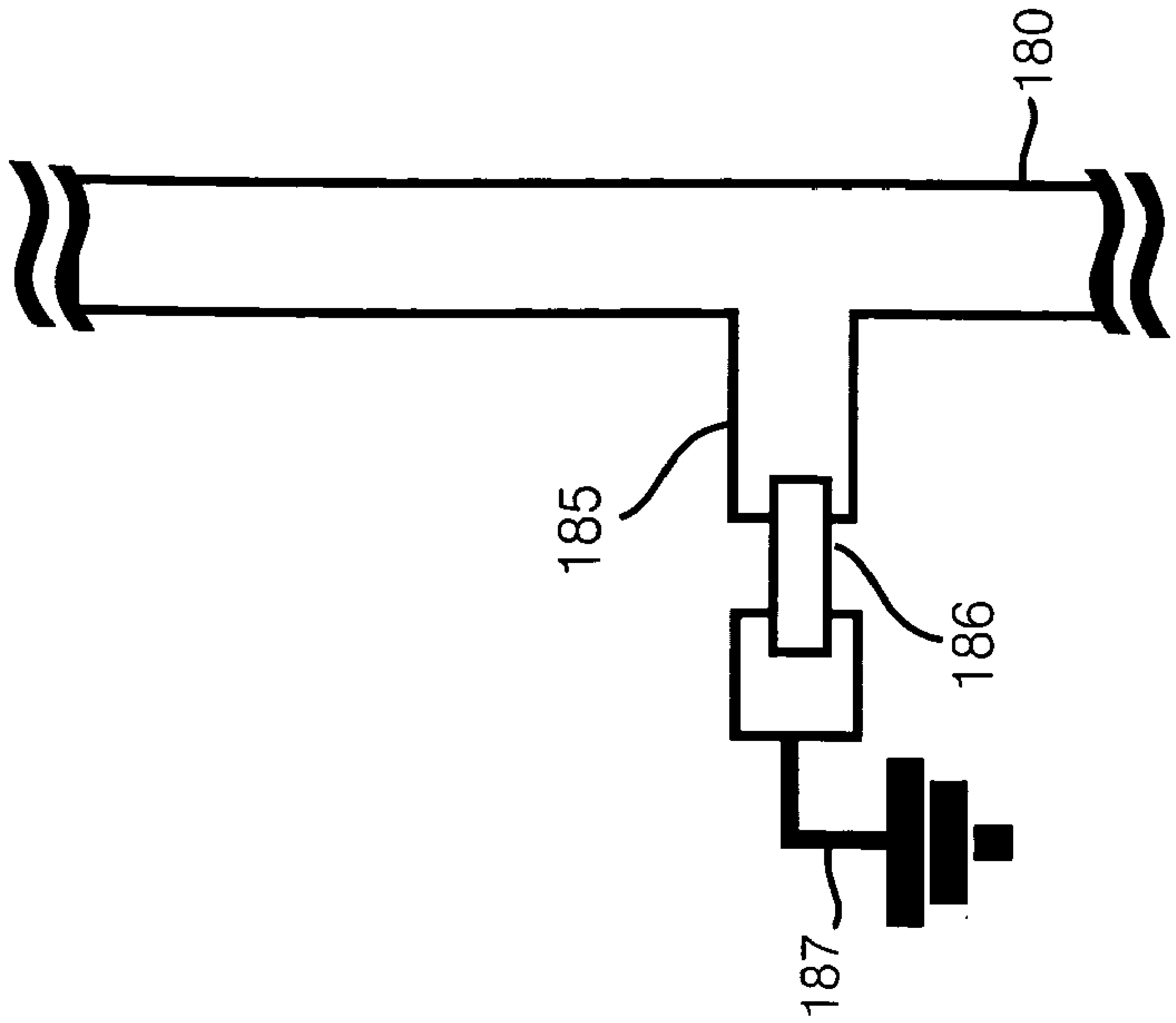

FIG. 16C

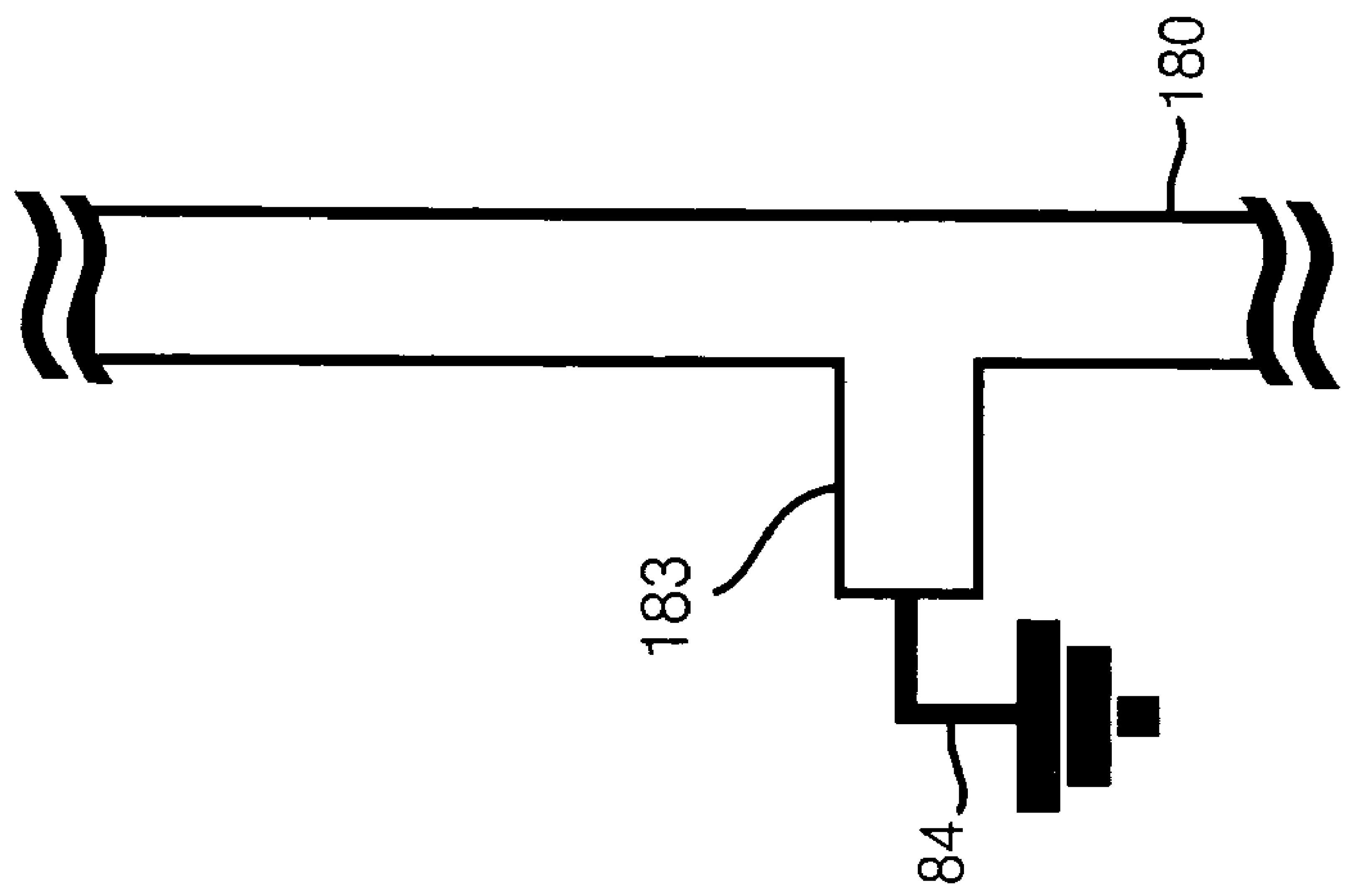

FIG. 16B

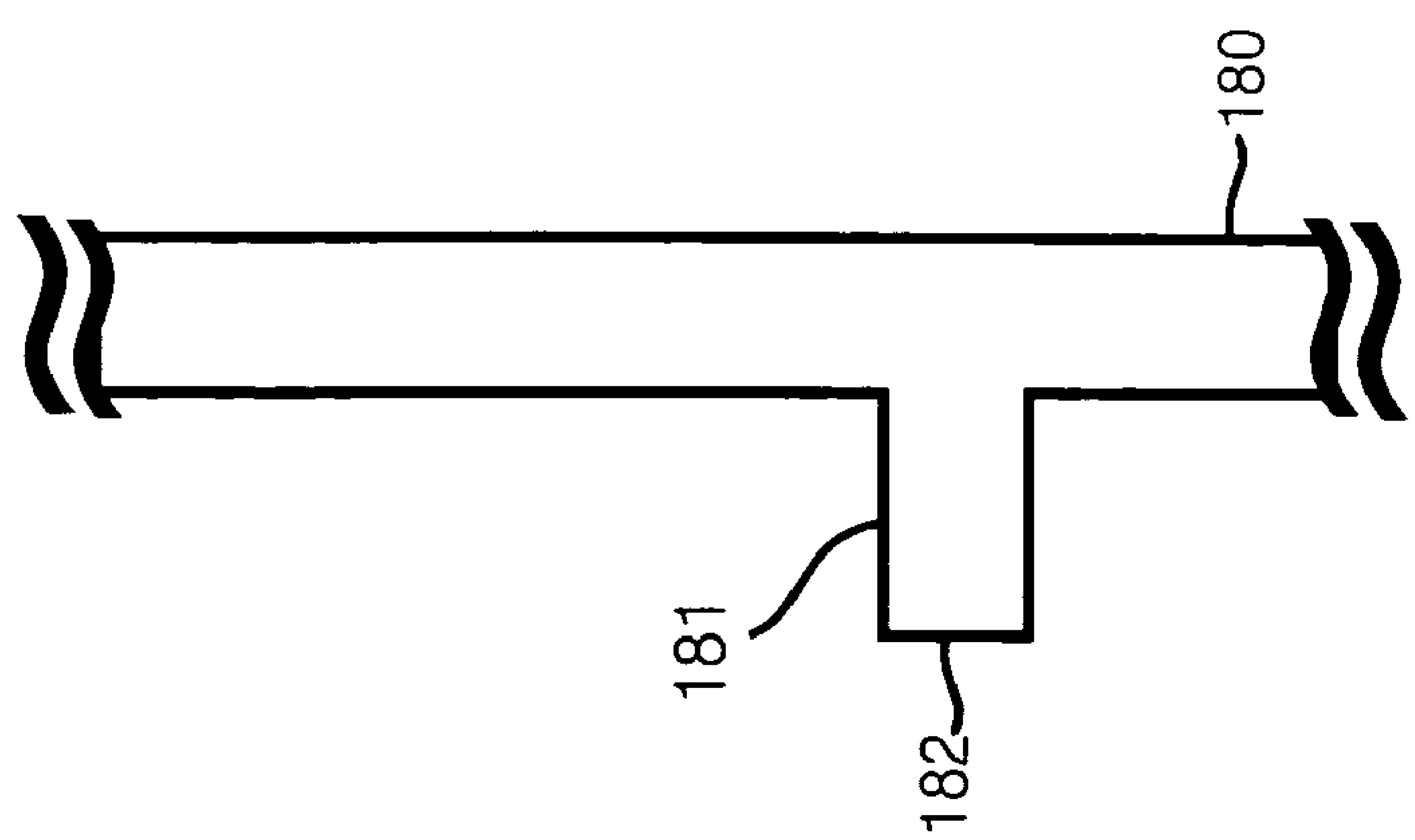

FIG. 16A

HIGH ISOLATION SIGNAL ROUTING ASSEMBLY FOR FULL DUPLEX COMMUNICATION

RELATED APPLICATIONS

This application is a continuation-in-part of international application PCT/US2007/026459, filed Dec. 29, 2007 which claims priority to U.S. provisional application 60/877,995, filed Dec. 29, 2006, and each of said applications is herein incorporated by reference.

TECHNICAL FIELD

The present invention relates to wireless transceivers that operate in full duplex mode providing the simultaneous transmission and reception of radio signals. In particular, but not exclusively, the present invention relates to wireless transceivers that are provided with a means to isolate signals transmitted by the transmitter of the wireless transceiver and received by a receiver of the wireless transceiver.

BACKGROUND OF THE INVENTION

Modern wireless communication, radar and radio frequency identification (RFID) systems often operate under full duplex operation. A wireless transceiver comprises of a local transmitter and a local receiver. Full duplex operation occurs when a local transmitter is actively transmitting RF signals during the same time that a local receiver is detecting RF signals and/or backscatter from the surrounding environment. The local transmitter and local receiver are typically in close proximity to one another and are often placed within a common enclosure. It is also desired to operate the full duplex system using a monostatic configuration, namely a configuration that uses a single antenna common to both the local transmitter and local receiver. In a typical transceiver, the transmitted and received signals are typically routed to and routed from the single antenna using a duplexing filter, circulator or directional coupler.

It is known that the operation of a local receiver during the time that a local transmitter is transmitting creates receiver problems as the transmitter energy leaks, couples and/or reflects into the receiver resulting in corruption, distortion, saturation and/or desensitization within the receiver. In some cases, a duplexing filter may be used to isolate the transmitted energy from the receiver if the transmitter and receiver are configured to operate at two different RF carrier frequencies that allow the duplexing filter to provide the required isolation between the transmitter and receiver. If the system is designed to operate with the transmitter and receiver using the same RF carrier frequency or with different transmit and receive frequencies that are close in RF carrier frequency such that the duplexing filter can not adequately provide the required isolation, then a circulator or directional coupler is typically used to isolate the transmitted signal from entering the receiver. Depending on the isolation performance of the circulator or coupler, the system performance may degrade when a portion of the transmitted energy leaks into the receiver.

Circulators and directional couplers are three and four port devices that are used to route RF and microwave signals between various ports within the component. A RF or microwave signal entering the circulator or coupler is expected to exit at a desired port(s) where one port is isolated from the incident signal. In practice, a portion of the incident signal leaks or couples to the isolated port. The ratio of the undesired leakage to the incident signal is often referred to as the isolation of the device. When referring to directional couplers, the isolation term is sometimes referred as the coupler directivity which is defined as the (dB) difference between the isolation and the coupling value of the directional coupler.

A basic circulator, **1**, is a three-port device that provides primary signal transmission between pairs of ports. A symbolic diagram of a circulator **1** is shown in FIG. **1**. Signals are routed between pairs of ports in the direction of circulation arrow **5**. For this example, the circulation arrow **5** in FIG. **1** shows a clockwise direction for signal paths. This circulation arrow **5** is used in the technical literature as a symbolic reference to the direction of signal paths within the circulator. Circulators can be manufactured to have either clockwise or counter-clockwise signal directions. A signal **6** entering the input port **2** will exit through the desired output port **3** following the clockwise circulation arrow **5**. Ideally, the signal **7** leaving the circulator **1** will have the same magnitude level as the input signal **6**. In practice, the signal **7** leaving the circulator **1** will have some reduction in amplitude due to losses and mismatches that occur inside the circulator. The signal **7** leaving the circulator **1** will also have a phase shift relative to the input signal **6**. Ideally, no portion of the input signal **6** should leave the third port **4**. This third port **4** is the isolated port. In practice, the isolated port **4** will have a signal level **8** reduced by approximately 20 dB when measured relative to the input signal **6**. In practice, junction circulators typically have a minimum isolation of 20-25 dB and lumped element circulators typically have a minimum isolation of 13 dB.

The circulator **1** can also be configured to operate with the input signal entering port **3** and exiting through port **4**. In this case port **2** is the isolated port. The circulator **1** can also be configured to operate with the input signal entering port **4** and exiting through port **2**. In this case port **3** is the isolated port.

A typically transceiver application using a monostatic antenna configuration is shown in FIG. **2**. In the case a local transmitter **9** generates a transmitted signal **6** that enters the input port **2** of the circulator **1**. The circulator **1** routes the signal to the common port **3**. The signal **7** leaves the circulator at the common port **3** and enters the antenna **12**. Any received signal **10** captured by the antenna **12** from the surrounding environment enters the common port **3** of the circulator **1** and is routed to the output port **4**. The desired received signal **13** leaving the output port **4** enters the local receiver **11**. If the system uses a local transmitter **9** and local receiver **11** that are operating simultaneously, then a portion of the signal **6** from the active transmitter **9** may couple or leak through the circulator **1** and enter the active receiver **11**. This undesired coupled signal **8** may reduce the performance of the receiver **11**.

For certain applications where additional losses in the receive path will not effect the required system performance, it is possible to replace the circulator with a directional coupler. In this configuration, the directional coupler is used to route the signals between the transmitter **9** to the antenna **12**, and from the antenna **12** to the receiver **11**. FIG. **3** shows a monostatic antenna configuration using a directional coupler **21**. In this configuration, the directional coupler **21** is positioned in order to transfer the signal **6** emitted from the local transmitter **9** to the antenna **12**. The directional coupler is typically a four-port device where one of the ports are terminated using a resistive termination **25**. The termination **25** is often matched to the characteristic impedance of the system, which is typically 50 ohms. In some cases, the termination **25** is included internally to the directional coupler which effectively makes the device into a three port component. A three port description for the directional coupler will be used throughout this disclosure. In the configuration shown in FIG.

3, the termination **25** is used to absorb energy coupled from the incident signal **6**. Ideally no portion of the incident signal **6** should leave port **24** which connects the directional coupler **21** to the receiver **11**. For signal reception from the surrounding environment, any received signals **10** captured by the antenna **12**, will enter the directional coupler **21** at common port **23**. A portion of the received signal **10** will be coupled to the output port **24**. The desired coupled signal **13** will then enter the receiver **11**. As the desired signal **13** is coupled to the output port **24** the amplitude level of the desired signal **13**, will be reduced by the coupling factor. In some full duplex systems, such as passive UHF RFID systems, this additional loss in received energy does not create difficulties when recovering the received information as these systems are generally forward link limited. Problems may occur when a portion of the incident transmitter signal couples or leaks into the receiver through the directional coupler which in turn may reduce receiver performance. In this case, a portion of the transmitted signal, **6**, may couple or leak through the directional coupler **21** and exit the output port **24**. This undesired coupled signal **8** will enter the receiver **11** and may reduce the performance of the receiver **11**.

In both configurations, shown in FIG. **2** and FIG. **3**, it is important that the receiver not be desensitized by any signal (s) coming from the system. Signals that could desensitize the receiver include signals received by the antenna and signals that leak or couple over from the transmit channel. If the signal received by the antenna from the surrounding environment is the signal of interest, then it is assumed that the system has been designed as not to desensitize the receiver when this signal is present. Therefore undesired receiver desensitization may occur when signals leak from the local transmitter into the local receiver. It is well known in industry, that fabricating a circulator with very high isolation (>30 dB) is often difficult and expensive. A typical junction circulator may have 20 dB isolation resulting in 1% of the transmit energy leaking into the receiver channel. This leakage signal may greatly affect the performance of the receiver in a full duplex system. As an example, a typical RFID system that uses a transmitter with an output power of 1 watt (+30 dBm) and a circulator with an isolation of 20 dB would have an unwanted signal entering the receiver of 10 mwatt (+10 dBm). This level of undesired signal would typically saturate and/or desensitize a low power mixer placed in the front end of the receiver.

DISCLOSURE OF INVENTION

It is an object of the present invention to provide a two way duplex wireless communication signal routing assembly wherein the channel to channel isolation is improved over prior art arrangements. In particular, the present invention relates to a signal routing assembly, a full duplex transceiver routing assembly and a full duplex transceiver routing assembly including carrier modulation. The signal routing assembly provides high isolation between two separate transmission signal paths utilizing a common port and typically configured to provide high isolation in the direction from the transmit channel transmission path to the receive channel transmission path in a full duplex system. The signal routing assembly allows the two transmission paths to operate using the same carrier frequencies. The signal routing assembly also allows the two transmission paths to operate using different transmit and receive frequencies. In an advantageous application the two different frequencies are close in frequency and are therefore inadequately filtered using a duplexing filter.

Briefly stated, the present invention provides a wireless communication device for effecting two way full duplex wireless communications, where the signal routing assembly accepts the first transmission signal at the input and outputs, a substantial portion of this signal at the common port of the signal routing assembly and a second transmission signal received at the common port from the surrounding environment or other parts of the system is routed through the signal routing assembly and a portion of the second transmission signal is delivered to output of the signal routing assembly. Relative to the output of the signal routing assembly, leakage signals from the first transmission signal are terminated inside the signal routing assembly in a typical system, a transmitter produces the first transmission signal and the signal routing assembly delivers a substantial portion of this signal to the common port of the signal routing assembly that is typically connected to the antenna. In full duplex operation, second transmission signals received at the antenna from the surrounding environment are routed to the receiver through the signal routing assembly from the common port to the output where at least a portion of a second transmission signal is delivered to the receiver. The signal routing assembly cancels a substantial portion of the transmitter leakage signal from entering the receiver.

In an embodiment of the present invention, the signal routing assembly includes a signal divider receiving the first transmission signal and dividing the first transmission signal into first and second divided transmission signals having substantially equal amplitudes and a first relative phase shift therebetween. First and second routing devices are provided each having at least first, second and third ports, and being configured to simultaneously deliver a signal at the first port to the second port and another signal at the second port to the third port each at functionally operative levels. The first and second routing devices receive the first and second divided transmission signals at the first ports and routes them to the second ports producing a first and second divided transmission output signal respectively. The first and second routing devices simultaneously output a first and second transmission leakage signal at the third ports respectively. The first and second routing devices receive, when present, third and fourth divided transmission signals at the second ports and routes them to the third ports producing third and fourth divided transmission output signals respectively. Further provided is a signal divider/combiner having first and second divider/combiner ports configured to combine the first and second divided transmission signals with a second relative phase shift therebetween to output a substantial portion of the first transmission signal to the common port of the signal routing device. The signal divider/combiner receives, when present, a second transmission signal and dividing the second transmission signal into third and fourth divided transmission signals having substantially equal amplitudes and a second relative phase shift therebetween. Further provided is a signal combiner having first and second combiner inputs receiving first and second transmission leakage signals and, when present, third and fourth divided transmission output signals. The signal combiner is configured to introduce a third relative phase shift into at least one of the signals applied to the combiner inputs such that; the first and second transmission leakage signals have approximately 180 degrees relative phase shift and arrive at approximately the same amplitude levels at the output to substantially cancel each other, and the third and fourth divided transmission output signals have approximately 0 degrees relative phase shift and arrive at approximately the same amplitude levels at the output to substantially combine with each other.

In an embodiment of the present invention the signal divider is optionally a quadrature hybrid. Alternatively, the signal divider may be embodied as an equal phase power dividing device with a phase shift introduced into one branch.

It is a feature of the present invention the signal combiner is optionally a quadrature hybrid. Alternatively, the signal combiner may be embodied as an equal phase power dividing device with a phase shift introduced into one branch. Such an equal phase power combiner will preferably include a resistive element in which undesired signals are dissipated.

It is a further feature of the present invention that the signal divider/combiner is embodied as a quadrature hybrid. Alternatively, the signal divider/combiner maybe embodied as an equal phase power divider/combiner with a phase shift introduced into one branch.

Yet another feature of the present invention is the use of circulators as the first and second routing devices. It is preferable that the first and second routing devices are electrically matched. Alternatively, one may embody the first and second routing devices as directional couplers.

It will be appreciated that any combination of the above noted embodiments of the signal divider, the signal divider/combiner, the signal combiner, and the routing devices may be used. Since two different examples of embodiments are discussed for each of the four devices, one will observe this yields sixteen combinations, the explicit recitation of which is unnecessary as such combinations will be understood.

It is a further feature of the present invention that in the signal routing assembly will deliver a substantial portion of the first transmission signal to the signal routing assembly common port where a substantial portion is in the range of 0.3 dB to 2.5 dB less in amplitude level relative to the first transmission signal when circulators are implemented as signal routing devices. Alternately, one may employ directional couplers as signal routing devices; therefore, a substantial portion is in the range of 0.2 dB to 4.0 dB.

It is a still further feature of the present invention that in the signal routing assembly will deliver a portion of the second transmission signal to the signal routing assembly output where a substantial portion is in the range of 0.3 dB to 2.5 dB less in amplitude level relative to the second transmission signal when circulators are implemented as signal routing devices. Alternately, one may employ directional couplers as signal routing devices; therefore, a substantial portion is in the range of 6.0 dB to 40.0 dB.

It is a still further feature of the present invention that the first and second transmission leakage signals produced by the first transmission signal substantially cancel each other such that a signal appearing at the output of the signal routing assembly is at least 22 dB below the amplitude level of the first transmission signal entering the signal routing assembly when circulators are used as signal routing devices. Preferably, this value will be at least 27 dB. Still more preferably, this value will be at least 37 dB.

Yet another feature of the present invention that the first and second divided transmission signals leaving the signal divider output ports may be amplified to increase the amplitude level of the divided transmission signals.

Yet still another feature of the present invention that the first and second divided transmission signals are modulated as to adjust the signal amplitude and/or phase.

Further features of the present invention include divider/combiner leakage cancellation configurations which compensate for leakage in the divider/combiner arising from the configuration of the signal divider/combiner producing a third transmission leakage signal, at the first divider/combiner port, which is a portion of the second divided transmission output signal and has an amplitude equal to an amplitude of the second divided transmission output signal multiplied by H and a phase shift $-\phi H$ relative to the second divided transmission output signal, and the signal divider/combiner further producing a fourth transmission leakage signal, at the second divider/combiner port, which is a portion of the first divided transmission output signal and has an amplitude equal to an amplitude of the first divided transmission output signal multiplied by H and a phase shift $-\phi H$ relative to the first divided transmission output signal.

A first embodiment of a divider/combiner leakage cancellation configuration includes a reflector device applied at the common port and configured to have a reflection coefficient R to reflect into the common port a portion of the substantial portion of the first transmission signal as a reflected signal of amplitude equal to an amplitude of the substantial portion of the first transmission signal multiplied by R and relative phase shift $-\phi R$. The configuration of the signal divider/combiner is so arranged as to divide the reflected signal into the first and second reflected divided signals having substantially equal amplitudes and a second relative phase shift therebetween, with the first and second reflected divided signals being respectively output at the first and second divider/combiner ports. The first routing device receives the first reflected divided signal and the third transmission leakage signal at the second port and produces, simultaneously at the third port, a first reflected divided output signal and a third transmission leakage output signal. The second routing device receives the second reflected divided signal and the fourth transmission leakage signal at the second port and produces, simultaneously at the third port, a second reflected divided output signal and a fourth transmission leakage output signal. The signal combiner has the first and second combiner inputs respectively receiving the third and fourth transmission leakage output signals, and respectively receiving the first and second reflected divided output signals. The signal combiner is so configured as to combine the first and second reflected divided output signals at the transmission signal output with the third and fourth transmission leakage output signals to effect substantial cancellation of the third and fourth transmission leakage output signals.

The divider/combiner leakage cancellation configuration has the configuration of the reflector device set to have the reflection coefficient R and the relative phase $-\phi R$ so as to effect the substantial cancellation of the third and fourth transmission leakage output signals by having R substantially equal H and $-\phi R$ substantially equal to $(-\phi H-90+2(\phi 8))$ wherein:

$\phi 8$ is a net electrical length of a portion of the common connecting line between said reflecting device and said common port of said signal divider/combiner.

A second embodiment of a divider/combiner leakage cancellation configuration includes a reflector device applied in a connection line between the second port of the first routing device and the first divider/combiner port of the signal divider/combiner and configured to have a reflection coefficient X to reflect into the second port of the first routing device a portion of the first divided transmission output signal as a reflected signal of amplitude equal to an amplitude of the first divided transmission output signal multiplied by X and relative phase shift $-\phi X$. The first routing device receives the reflected signal and the third transmission leakage signal at the second port and produces, simultaneously at the third port a reflected output signal and a third transmission leakage output signal. The second routing device receives the fourth transmission leakage signal at the second port and produces, simultaneously at the third port a fourth transmission leakage output signal. Finally, the signal combiner has the first and second combiner inputs respectively receiving the third and fourth transmission leakage output signals, and the first combiner input receiving the reflected output signal. The signal combiner is so configured as to combine a portion of the reflected output signal at the transmission signal output with the third and fourth transmission leakage output signals to effect substantial cancellation of the third and fourth transmission leakage output signals wherein the configuration of the reflector device is sot to have a reflection coefficient equal to X and the relative phase −ϕX so as to effect the substantial cancellation of the third and fourth transmission leakage output signals.

The second embodiment of a divider/combiner leakage cancellation configuration includes X being set substantially equal to 2H and −ϕX being set substantially equal to (−ϕH−90−2(ϕ4)+2(ϕ6)) wherein:

- ϕ4 is a net electrical length of a first connecting line connecting the second port of the first routing device to the first divider/combiner port;
- ϕ4 is a net electrical length of a second connecting line connecting the second port of the second routing device to the second divider/combiner port; and
- ϕ6 is a net electrical length of a portion of the first connecting line between the reflecting device and the second port of the first routing device.

A third embodiment of a divider/combiner leakage cancellation configuration is constructed and functions as does the second embodiment with the exception that the reflector device is applied in a connection line between the second port of the second routing device and the second divider/combiner port of the signal divider/combiner.

A fourth embodiment of a divider/combiner leakage cancellation configuration is constructed as a combination of the second and third embodiment and has a first reflector device applied in a connection line between the second port of the first routing device and the first divider/combiner port of the signal divider/combiner, and a second reflector device applied in a connection line between the second port of the second routing device and the second divider/combiner port of the signal divider/combiner so as to effect an imbalance resulting in cancellation of the third and fourth transmission leakage output signals.

The reflector devices in the above cancellation configurations are an open stub, a shorted stub, or a reactive component selected from the group consisting of a capacitor and an inductor.

The above, and other objects, features and advantages of the present invention will become apparent from the following description read in conjunction with the accompanying drawings, in which like reference numerals designate the same elements. The present invention is considered to include all functional combinations of the above described features and is not limited to the particular structural embodiments shown in the figures as examples. The scope and spirit of the present invention is considered to include modifications as may be made by those skilled in the art having the benefit of the present disclosure which substitute, for elements presented in the claims, devices or structures upon which the claim language reads or which are equivalent thereto, and which produce substantially the same results associated with those corresponding examples identified in this disclosure for purposes of the operation of this invention. Additionally, the scope and spirit of the present invention is intended to be defined by the scope of the claim language itself and equivalents thereto without incorporation of structural or functional limitations discussed in the specification which are not referred to in the claim language itself.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a prior art diagram of a circulator showing signal paths for desired and undesired signals that pass through the device;

FIG. **2** is a prior art diagram of a complete transceiver system using a circulator to route signals from the transmitter to the antenna and from the antenna to the receiver. Also shown is the undesired signal entering the receiver;

FIG. **3** is a prior art diagram of a complete transceiver system using a directional coupler to route signals from the transmitter to the antenna and from the antenna to the receiver. Also shown is the undesired signal entering the receiver;

FIG. **4** is a diagram of an embodiment of the routing device;

FIG. **5** is a diagram of an embodiment showing details of the routing device;

FIG. **6** is a diagram of an embodiment showing signal paths proceeding from the transmitter to the circulators;

FIG. **7** is a diagram of an embodiment showing signal paths proceeding from the circulators to the receiver and termination;

FIG. **8** is a graph of measured results for the isolation between the transmit channel to the receive channel;

FIG. **9** is a graph measured results for the isolation between the receiver channel to the transmit channel;

FIG. **10** is a diagram of an embodiment of the routing device using directional couplers as the routing device;

FIG. **11** is a diagram of an embodiment of the routing device using equal-phase power dividers and equal-phase power combiners that include a phase shift network;

FIG. **12** is a diagram of an embodiment of the routing device including modulators and amplifiers to modulate and amplify the input transmission signal;

FIG. **13** is a diagram of an embodiment showing signal paths proceeding from a leakage source to the receive channel;

FIG. **14** is a diagram of an embodiment showing the signal paths from a reflective device to the receive channel;

FIG. **15** is a diagram of an embodiment showing the signal paths from a reflective device to the receive channel;

FIG. **16**A is a diagram of an embodiment showing the reflective device configured as an open stub;

FIG. **16**B is a diagram of an embodiment showing the reflective device configured as a shorted stub; and

FIG. **16**C is an embodiment showing the reflective device configured as a reactive lumped element.

DETAILED DESCRIPTION OF THE INVENTION

Improvements in transmit to receive isolation for three-port signal routing devices can be provided using a combination of signal dividers with the proper signal phasing and conventional three port components that when properly connected will combine signals at the desired ports and cancel signals at the isolated ports.

The generalized construction of the three port signal routing device is shown in FIG. **4**. The routing device **50** has one input port **51**, one common port **52** and one output port **53**. The input signal is received at the input port **51** and routed to the input **59** of a signal divider **54**. Input port **51** is typically connected to the local transmitter. Signal divider **54** divides the transmission signal into first and second divided transmission signals output at ports **60** and **61** and having substantially equal amplitudes and a first relative phase shift therebetween. The signal divider **54** is any of a quadrature hybrid, or an equal phase power splitter, e.g., a Wilkinson power splitter, a resistive divider, a T-junction or a reactive T, with a phase shift network applied to one output, or other device so functioning to divide a signal.

The first and second divided signals are routed to first and second routing devices, **55** and **56**, each having at least first, second and third ports. The divided signals enter the first ports and are routed to the second ports, the outputs of which are applied to the signal divider/combiner **57**. The signal divider/combiner **57** is any of a quadrature hybrid, or an equal phase power splitter, e.g., a Wilkinson power splitter, a resistive divider, a T-junction or a reactive T, with a phase shift network applied to one output, or other device so functioning to combine the signals from the second ports of routing devices **55** and **56**. The combined signal exits the divider/combiner **57** at port **66** and is routed to the common port **52**. Common port **52** is typically connected to an antenna for signal transmission and reception. Any signal entering the routing device **50** at the common port **52** is routed to port **66** of the signal divider/combiner **57** which divides the received signal into third and fourth divided transmission signals output at ports **64** and **65** and having substantially equal amplitudes and a first relative phase shift therebetween.

The third and fourth divided signals are routed to first and second routing devices, **55** and **56**. The divided signals enter the second ports and are routed to the third ports, the outputs of which are applied to the signal combiner **58**. The signal combiner **58** is any of a quadrature hybrid, or an equal phase power splitter, e.g., a Wilkinson power splitter, a resistive divider, a T-junction or a reactive T, with a phase shift network applied to one output, or other device so functioning to combine the signals from the third ports of routing devices **55** and **56**. The combined signal exits the combiner **58** at port **73** and is routed to the output port **53**. Output port **53** is typically connected to the local receiver.

The routing devices, **55** and **56**, are preferably matched circulators which provide some degree of isolation between the first ports and the third ports. Alternatively, the routing devices, **55** and **56**, are directional couplers.

The first and second routing devices, **55** and **56**, are devices intended to transfer a first signal from the first port to the second while simultaneously transferring another second signal entering the second port to the third while preventing the first signal from appearing at the third port. This is the idealized concept of such a routing device. However, in actual embodiments some of the first signal undesirably leaks through to the third port. The amount of this leakage is characterized by the isolation of the device wherein the greater the isolation (measured generally in decibels or dBs) is the higher the isolation value is. For the purposes of this disclosure the routing devices are characterized by transmission coefficients including:

- s21 being a transmission coefficient from the first port to the second port;
- s32 being a transmission coefficient from the second port to the third; and
- s31 being a transmission coefficient from the first port to the third port;

wherein s21 is greater than s31, and s32 is greater than s31.

For the purposes of this disclosure intended signal transfers are considered transfers at functionally operative levels meaning a level at which the signals transferred effect a desired function in the application of the device. Hence, applying this terminology to a simple switch transferring a signal, when the switch is on it would transfer a signal from an input to an output at a functionally operative level. If the switch is off, some leakage may occur resulting in a portion of the signal appearing at the output, this portion of the signal would not be considered to be at a functionally operative level since it would be attenuated to a level not intended to effect operation and not effecting a desired operation.

The signal combiner **58** has first and second combiner inputs and a received signal output connected to the receiver. The first and second combiner inputs are respectively connected to the third ports of the first and second routing devices, **55** and **56**, to accept the received signals from the common port **52**. The signal combiner **58** introduces a phase shift into signals applied to at least one of the first and second combiner inputs such that the received signals from the common port **52** are combined substantially in phase to produce the received signal at a received signal output which connects to the receiver. Transmission leakage signals which leak from the first ports to the third ports of the routing devices, **55** and **56**, are substantially phase shifted relative one another 180 degrees at the received signal output to substantially cancel each other. The signal combiner **58** may be a quadrature hybrid, or an equal phase power splitter, e.g., a Wilkinson power splitter/combiner, a resistive divider, a T-junction or a reactive T, with a phase shift network applied to one of two inputs.

In the routing device **50**, connecting lines **62**, **63**, **67**, **68**, **69** and **70** interconnect the components and are described in more detail below. It is understood that components may be directly connected to each other and connecting lines omitted where feasible. In the preferred embodiment connecting lines **62** and **63** are electrically matched, connecting lines **67** and **68** are electrically matched and connecting lines **69** and **70** are electrically matched. However, it will be understood that it is not necessary that each of these pairs of lines be matched provided that overall phase shifts of and attenuations of signals are such that the transmitted signals are properly combined for transmission to the antenna and received signals are properly combined for transmission to the receiver. In order to provide adequate transmit channel to receive channel isolation, the overall phase shifts and insertion losses of the connecting lines or equivalents should present an overall phase shift and insertion loss introduced by connecting lines **62**, **63**, **69** and **70**, or their equivalents, present the transmission leakage signals of substantially equal amplitude and phase shifted relative one another about 180 degrees at the received signal output to substantially cancel each other.

In the preferred embodiment discussed below, improved isolation of the routing device **50** is achieved by the effective cancellation of the transmission leakage signal at the received signal output. The phase shifting of these undesired signals to effect cancellation should be such that transmit to receive isolation of at least 30 dB is achieved over a frequency range associated with the system use. More preferably, the insertion losses and phase shifts should effect matching resulting in at least 35 dB isolation over the frequency range. Still more preferably, the insertion losses and phase shifts should effect matching resulting in at least 40 dB isolation over the frequency range. Matching tolerances and effectiveness are discussed below.

It will be additionally appreciated from this disclosure that the phase shifts discussed herein are relative between the respective signals discussed and do not include multiples of 360 degrees electrical length difference that may exist in one connection over another. In other words and as merely an example, for the purposes of this disclosure, unless noted otherwise, a phase shift of 360 degrees or multiples thereof between signals is not considered to be a portion of a relative phase shift. Hence, a signal which is shifted 450 degrees relative another signal, is considered to be shifted 90 degrees for the purposes of this disclosure. Accordingly, it is understood that relative shifts and limitations related thereto recited herein do not exclude the addition of integer multiples of 360 degrees unless specifically stated. While it is preferable that electrical length differences of greater than 360 degrees are not introduced, such difference are not considered to be outside the scope of the present invention.

It will also be appreciated in view of this disclosure that practical production tolerances will result in slight differences in electrical characteristics between the connecting lines and between the first and second routing devices. Tuning elements and/or phase adjustment may be inserted along any connecting line in order to adjust the amplitude and phase of the signal traveling along the line. Tuning the signal may improve the isolation between the transmit channel and receive channel by compensating for any differences between the signal paths and components. Such tuning elements may include stubs or lumped components or other devices as are known by those skilled in the art. Additionally, for the purposes of this disclosure and unless stated otherwise, the connecting lines shown interconnecting components are not intended to exclude insertion of other components in those connecting lines for tuning, amplification or other purposes provided that the cancellation of the transmission leakage signals are achieved at the signal combiner **58**.

Referring to FIG. **5**, details of a preferred embodiment of the present invention are described herein wherein the generalized internal components of the routing device **50** as disclosed above are embodied in devices used in implementation of the preferred embodiment. It is understood that the above discussion with relation to the generalized components and interconnections shown in FIG. **4** applies to the preferred embodiment shown in FIG. **5**.

In FIG. **5** the routing device **50** uses three quadrature hybrids, an input quadrature hybrid **110**, a common quadrature hybrid **111** and an output quadrature hybrid **112**, and first and second circulators, **100** and **101**, connected in such a way as to prevent unwanted transmission energy from the transmitter from entering the receiver. The input quadrature hybrid **110**, common quadrature hybrid **111** and output quadrature hybrid **112** need not be of the same construction but the first and second circulators, **100** and **101**, are preferably of the same construction and are more preferably electrically matched. If dictated by physical constraints of the application, the first and second circulators, **100** and **101**, need not be physically identical, e.g., they may be mirror images or otherwise physically differ, but the first and second circulators, **100** and **101**, are preferably electrically similar in both amplitude and phase characteristics.

The transmitter output is connected to the input port **51** of the routing device **50**. The receiver input is connected to output port **53** of the routing device **50**. The antenna is connected to common port **52**. The transmission signal enters input port **51**, travels along transmission signal input connecting line **115** and enters an input port **116** of the input quadrature hybrid **110**. This signal that enters the input quadrature hybrid **110** is split into two substantially equal amplitude signals with quadrature phase. One half of the signal input leaves port **118** with a relative phase of −90 degrees in relation to another half of the signal input that leaves through port **117**. An isolated port **119** of the input quadrature hybrid **110** is terminated with a termination **120** in order to absorb reflected energy that may be entering port **118** and port **117**. The termination **120** will also absorb energy that leaks from the input port **116** to the isolated port **119**.

The first half of the signal derived from the transmission signal leaves port **118** of input quadrature hybrid **110**, propagates down connecting line **121** and enters port **123** of the first circulator **100**. Rotation of the first circulator **100** is shown as clockwise which implies that a signal entering port **123** will leave through port **125** of the first circulator **100**. This signal continues along connecting line **130** until it enters the port **131** of the common quadrature hybrid **111**. The common quadrature hybrid **111** is used for both transmitting signals and receiving signals through the routing device **50**. The signal entering port **131** of the common quadrature hybrid **111** is split into two substantially equal amplitude signals with quadrature phase. One half of the signal input leaves port **135** with a relative phase of −90 degrees in relation to another half of the signal input that leaves through port **134**.

The second half of the signal derived from the transmission signal leaves port **117** of input quadrature hybrid **110**, propagates down connecting line **122** and enters port **124** of the second circulator **101**. Rotation of the second circulator **101** is shown as counter-clockwise which implies that the signal entering the port **124** will leave through port **126**. This signal continues along feed line **132** and enters port **133** of the common quadrature hybrid **111**. The signal entering port **133** of the common quadrature hybrid **111** is split into two substantially equal amplitude signals with quadrature phase. One half of the signal input leaves port **134** with a relative phase of −90 degrees in relation to another half of the signal input that leaves through port **135**.

The equal amplitudes and relative phases of the two signals leaving port **134** of common quadrature hybrid **111** result in signal addition of the transmitted signal that enters the transmitter input port **51**. The transmitted signal travels down connecting line **137** and leaves the routing device **50** at the common port **52**. The equal amplitudes and relative phases of the two transmitted signals leaving port **135** of common quadrature hybrid **111** result in signal cancellation at the output port **135**. In the ideal case, no portion of the transmitted signal is absorbed in the termination **136** connected to the common quadrature hybrid **111** at port **135**. In the ideal case, the transmitted signal entering the input port **51** of the routing device **50** is first divided and then recombined to leave the routing device **50** at common port **52**. In practice, the total transmitted energy leaving port **52** will be reduced by the insertion loss of components and connecting lines used in routing device **50**.

The received signal entering the common port **52** of the routing device **50** travels along connecting line **137** and enters port **134** of common quadrature hybrid **111**. The signal that enters the common quadrature hybrid **111** is split into two substantially equal amplitude signals with quadrature phase. One half of the signal input leaves port **133** with a relative phase of −90 degrees in relation to another half of the signal input that leaves through port **131**. The isolated port **135** of the common quadrature hybrid **111** is terminated with a termination **136** in order to absorb any reflected received energy that may be entering port **131** and port **133**. The termination **136** will also absorb energy that leaks from the input port **134** to the isolated port **135**.

The first half of the received signal leaving port **133** travels along connecting line **132** and enters the second circulator **101** at the common port **126**. Rotation of the second circulator **101** is shown as counter-clockwise which implies that the signal entering the port **126** will leave through output port **128**. This signal continues along feed line **141** and enters port **143** of the output quadrature hybrid **112**. The signal entering port **143** of the output quadrature hybrid **112** is split into two substantially equal amplitude signals with quadrature phase.

One half of the signal input leaves port **145** with a relative phase of −90 degrees in relation to another half of the signal input that leaves through port **144**.

The second half of the signal derived from the received signal leaves port **131** of common quadrature hybrid **111**, propagates down connecting line **130** and enters the common port **125** of the first circulator **100**. Rotation of the first circulator **100** is shown as clockwise which implies that the signal entering the common port **125** will leave through port **127**. This signal continues along feed line **140** and enters port **142** of the output quadrature hybrid **112**. The signal entering port **142** of the output quadrature hybrid **112** is split into two substantially equal amplitude signals with quadrature phase. One half of the signal input leaves port **144** with a relative phase of −90 degrees in relation to another half of the signal input that leaves through port **145**.

The equal amplitudes and relative phases of the two signals leaving port **144** of output quadrature hybrid **112** result in signal addition of the received signal. The received signal travels down connecting line **147** and leaves the routing device **50** at the receive port **53**. The equal amplitudes and relative phases of the two signals leaving port **145** of output quadrature hybrid **112** result in signal cancellation at the output port **145**. In the ideal case, no received signal entering the common port **52** of the routing device **50** is absorbed in the termination **146** connected to the output quadrature hybrid **112** at output port **145**. In the ideal case, the received signal entering the common port **52** of the routing device **50** is first divided by common quadrature hybrid **111** and then recombined by output quadrature hybrid **112** to leave the routing device **50** at receive port **53**. In the practical the total received energy leaving receive port **53** will be reduced by the insertion loss of components and connecting lines used in routing device **50**.

It will be understood by those skilled in the art in view of this disclosure that the rotation of first circulator **100** and second circulator **101** in FIG. **5** was chosen for clarity in the diagram and that the rotation direction of the first and second circulators, **100** and **101**, can be changed as long as the interconnecting lines are appropriately arranged to route the signals as described above.

The routing device **50** is designed to provide isolation between the transmit channel to the receive channel from any portion of the transmit signal that may couple through the first circulator **100** and second circulator **101**. In the ideal case, any signal entering the input port **123** will leave through common port **125** and no portion of the transmitted signal will be seen at output port **127**. In practice the first circulator **100** has limited amount of isolation between the input port **123** and output port **127**. This undesired coupling of energy from the input port **123** to the output port **127** is caused predominately by practical limitations in the circulator design and mismatch between common port **125** and connection to the connecting line **130**. The portion of the transmitted signal that couples through first circulator **100** will travel along connecting line **140** and enter the output quadrature hybrid **112** at the input port **142**. The coupled signal is split into two equal amplitude signals in quadrature phase. One half of the signal is delivered to the isolated port **145** and one half is delivered to the output port **144**.

In the ideal case any signal entering the input port **124** will leave through common port **126** and no portion of the transmitted signal will be seen at output port **128**. In practice the second circulator **101** has limited amount of isolation between the input port **124** and the output port **128**. This undesired coupling of energy from the input port **124** to the output port **128** is caused predominately by practical limitations in the circulator design and mismatch between common port **126** and connection to the connecting line **132**. The portion of the transmitted signal that couples through second circulator **101** will travel along connecting line **141** and enter the output quadrature hybrid **112** at the input port **143**. The coupled signal is split into two equal amplitude signals in quadrature phase. One half of the signal is delivered to the isolated port **145** and one half is delivered to the output port **144**.

It can be shown that undesired coupled signals through first circulator **100** and second circulator **101** will result in two equal amplitude signals appearing at the isolated port **145** and two equal amplitude signals at output port **144**. It can also be shown that the phase relationship between these signals will result in signal addition at the isolated port **145** and signal cancellation at output port **144**. In this way, any energy that is coupled through first circulator **100** and second circulator **101** will be terminated by termination **146** and no undesired coupled energy will be delivered to output port **144**. Output port **144** can be connected to the receive channel of a full duplex transceiver thus providing high isolation between the transmit channel to the receive channel.

As previously mentioned, it is expected that circulators **100** and **101** have approximately the same electrical performance in both amplitude and phase in order to maintain the quadrature phase relationship developed by the input quadrature hybrid **110**. Tuning elements and/or phase adjustment may be inserted along any feed line in order to adjust the amplitude and phase of the signal traveling along the line. Tuning the signal may improve the isolation between the transmit channel and receive channel by compensating for any differences between the signal paths. It is also found that tuning elements, such as small stubs, placed on connecting line **130** and/or connecting line **132** and placed in close proximity to circulator common port **125** and/or circulator common port **126** can greatly improve the amount of isolation between the transmit and receive channels. The tuning element or elements achieve a better electrical match between the two circulators.

FIG. **6** shows the routing device **50** for signals that travel from the transmitter to the first circulator **100** and the second circulator **101**. The complex input signal S**1** to the routing device **50** will be assumed to have voltage amplitude equal to 1 and phase equal to 0 degrees. TABLE 1 summarizes the amplitudes and relative phases for the signals traveling from the input port **51** up to the first and second circulators **100** and **101** respectively. As shown in FIG. **6**, the input signal S**1** enters the input quadrature hybrid **110** at port **116** and the signal is divided into two equal amplitude signals with quadrature phase. The signal S**2** leaving port **118** has amplitude equal to 1/sqrt(2) and relative phase equal to −90 degrees and the signal S**3** leaving port **117** has amplitude equal to 1/sqrt(2) and relative phase equal to 0 degrees. The input quadrature hybrid **110** can also be configured with these two connections swapped. In this case, the connections to the other two quadrature hybrids would also need to be swapped in order to maintain the same performance. The two output signals from the first quadrature hybrid **110** travel along connecting lines **121** and **122** respectively. The length of transmission line for connecting lines **121** and **122** introduce an additional phase shift of −ϕ1 to each signal S**4** and S**5**.

TABLE 1

Signal	Amplitude	Phase
S1	1	0
S2	1/sqrt(2)	−90

TABLE 1-continued

Signal	Amplitude	Phase
S3	1/sqrt(2)	0
S4	1/sqrt(2)	$-90-\phi 1$
S5	1/sqrt(2)	$-\phi 1$
S16	B/sqrt(2)	$-90-\phi 1-\phi B$
S17	B/sqrt(2)	$-\phi 1-\phi B$
S18	B	$-90-\phi 1-\phi B-\phi 3$
S19	0	

FIG. **7** shows the signal paths for the coupled or leakage signals from the input port **123** and port **124** of circulators **100** and **101** respectively to the output ports **127** and **128**. The upper and lower sections of the routing device **50** are not shown for clarity. For this analysis, it is assumed that any undesired signal that couples through the circulator will experience a change in amplitude equal to B and a phase shift equal to $-\phi B$. The signal S**16** from the output port **127** will have an amplitude equal to B/sqrt(2) and relative phase of $(-90-\phi 1-\phi B)$ degrees. The signal S**17** on the output port **128** will have amplitude equal to B/sqrt(2) and relative phase of $(-\phi 1-\phi B)$ degrees. These signals travel along feed lines **140** and **141** respectively. The length of transmission line for connecting lines **140** and **141** introduce an additional phase shift of $-\phi 3$ to each signal. Each input signal to the output quadrature hybrid **112** is divided in half. A relative phase shift of −90 degrees is introduced into the signal passing from the port **143** over to the port **145**. A relative phase shift of −90 degrees is introduced into the signal passing from the port **142** over to the port **144**. A relative phase shift of 0 degrees is introduced into the signal passing from the port **142** over to the port **145**. A relative phase shift of 0 degrees is introduced into the signal passing from the port **143** over to the port **144**. Vector addition of the output signals at port **144** of the quadrature hybrid **112** will show signal cancellation resulting in output amplitude S**19** of 0. Vector addition of the output signals at port **145** of the quadrature hybrid **112** will show signal addition resulting in output amplitude S**18** of B. Output port **144** is connected to the receive channel to prevent undesired circulator coupling or leakage from entering the receiver. Port **145** is connected to termination **146** in order to terminate the undesired energy that coupled through the circulators. In some systems, the energy at the terminated port **145** can be measured and used as an indication of the operation of the circulators. For example, if a large signal level is measured at the port **145** then it may indicate a problem with the one or both circulators, as most of the signal is being coupled across the circulator and not properly transmitted through the antenna into the surrounding environment.

The above derivation assumed that the two signal paths were balanced in both relative amplitude and relative phase in order that signal cancellation would occur at the output port **144** of the routing device **50**. Tolerances in the components and connecting lines may result in a degradation of the transmit-to-receive isolation provided by the routing device **50**. A study of the amplitude balance and phase balance for the signals entering the quadrature hybrid **112** can show what level of transmit-to-receive isolation is achievable in the routing device **50**. Also note, that the quadrature hybrid **112** or other power combiner may also have relative amplitude and phase imbalance that may reduce the isolation performance. In this case, the tolerance within the quadrature hybrid **112** or other power combiner can be considered as part of the following analysis. TABLE 2 shows the required amplitude and phase balance between two signal paths that would result in a 30 dB and 40 dB isolation between the transmit channel to receive channel. TABLE 2 lists the required relative amplitude and phase tolerance as a function of the signal level of the undesired coupling. It is assumed that the amplitude and phase imbalances are created by differences in the insertion loss and electrical lengths of the connecting lines, electrical variations between the ports of the power dividers and combiners and electrical variations between the pair of circulators. For example, circulators that have a poor isolation such as 10 dB, would require tighter tolerance in the balance between the two combined signals in order to achieve a high isolation between transmit and receive channels.

As a numerical example using the TABLE 2, if the required transmit-to-receive isolation is 30 dB using the routing device **50** and the circulator isolation having a value of 15 dB, then the relative amplitude balance between the two paths would need to be within the range of +3.8 dB/−1.6 dB. This analysis assumes that the phase balance is ideal. Using this same example but with an ideal amplitude balance, the relative phase balance between the two paths would be +/−20.5 degrees. For the signal routing assembly having both amplitude and phase imbalances, a Monte Carlo analysis is one technique that can be used to estimate the range of tolerances required to achieve a certain level of isolation between the transmit channel to receive channel. For example, using a circulator with isolation of 10 dB would require a relative amplitude balance of +1.2 dB/−0.8 dB and a relative phase balance +/−10 degrees in order to achieve approximately 30 dB isolation between the transmit channel to receive channel. There are other combinations of amplitude and phase tolerances that can achieve this isolation value.

In practice, amplitude and phase adjustments within the signal routing assembly **50** can be implemented to improve the final isolation of the network. In this case, amplitude and phase shift tuning, using such components as attenuators and lengths of transmission lines, can adjust the balance between the two signal paths in order to optimize the isolation between the transmit channel and receive channel. In addition, proper selection of the components, and when using a printed circuit board, symmetrical layout of the connecting lines, can result in amplitude and phase balances within +/−0.3 dB and +/−5 degrees with minimal tuning at an operation frequency of 915 MHz. These tolerances can achieve approximately a 35 dB isolation between transmit to receive channels.

TABLE 2

Undesired Signal Level (dB)	Amplitude Balance (dB)	Phase Balance (deg)
Transmit to Receive Isolation = 30 dB		
5	+1/−0.9	+/−6.4
10	+1.9/−1.6	+/−11.4
15	+3.8/−2.6	+/−20.5
20	+8.7/−4.2	+/−36.9
25	+inf/−6.5	+/−68.4
Transmit to Receive Isolation = 40 dB		
5	+/−0.3	+/−2.0
10	0.6/−0.5	+/−3.6
15	+1/−0.9	+/−6.4
20	+1.9/−1.6	+/−11.4
25	+3.8/−2.6	+/−20.5

From the above analysis and data, it will be understood by those skilled in the art that amplitude levels that are exactly the same or phase differences that are exactly 180 degrees, while desirable for the practice of this invention, are not required for the practice of this invention. As indicated in the above Table 2, the amplitude balance and phase balance required to practice the invention will depend on the desired transmit to receive channel isolation and the undesired signal level produced by the transmission leakage through the circulators. The undesired signal levels are presented in terms of attenuation of the transmission input signal, i.e., the attenuation of the transmission signal passed from port one of the routing devices, **100** and **101**, which results in the undesired signal appearing at the combining assembly. Thus, for the present invention, the requirements for approximately the same level signals and approximately the desired phase shift, e.g., 180 degrees, are understood to mean within tolerances yielding a desired isolation based on the characteristics of the signal routing devices, **100** and **101**. Such tolerances are illustrated in the Table 2 for transmit to receive channel isolation levels of 30 dB and 40 dB. The undesired signal referred to is the leakage transmission signal from one of the routing devices, **100** and **101**, the value in dB represents the attenuation ratio relative to the divided transmission signals at the first ports of the routing devices, **100** and **101**, for the leakage transmission signal.

In practice the amount of cancellation in the signal combiner **112** varies with the matching of the signal. It is considered that the undesired leakage signals substantially cancel when the receiver front end functions adequately. Depending on the application, the amount of cancellation necessary will vary on the amount of leakage in the routing devices **100** and **101**. In applications such as RFID tag excitation and reading, it may be acceptable that the first and second leakage signals substantially cancel each other such that a signal appearing at the received signal output of the signal combiner **112** which is produced by the transmission signal, and does not include any signal received by the antenna by reception of radiation, is at least 20 dB below a level of the desired transmission signal. Preferably, such a signal is 25 dB down, more preferably such a signal is 30 dB down, and still more preferably such a signal is 40 dB down. It should further be noted that this cancellation is achieved routing the signals using passive components without employing active cancellation.

FIG. **8** shows two measured results for transmit channel to receive channel isolation. The upper curve **150** in FIG. **8** is the isolation for the standard lumped element type circulator as shown in FIG. **1**. The lumped element circulator was manufactured for best performance in the 902 MHz to 928 MHz frequency range. This measurement was made by measuring the difference in the leakage signal level **8** relative to the input signal **6** as shown in FIG. **1**. A routing device was fabricated using a printed circuit etched onto a FR-4 dielectric substrate. The routing device was fabricated with two lumped element circulators of the same type used in the first measurement **150** shown on FIG. **8**. The circulators were manufactured for best performance in the 902 MHz to 928 MHz frequency range. The lower curve **151** in FIG. **8** was measured using the preferred embodiment of routing device **50** as shown in FIG. **5**. This measurement was made by measuring the signal level between receive channel output **53** relative to the signal level at the transmit channel input **51**. It is shown from the measured results that the routing device **50** provides a much higher isolation over a much wider range of frequencies. For example, the measured worst case isolation over the operating band of 860 MHz to 960 MHz is 13 dB for the standard lumped element circulator and 35 dB using the preferred embodiment for the routing device **50**.

FIG. **9** shows the measured results for the receive channel to transmit channel isolation. The upper curve **152** shows the measured isolation for the standard lumped element circulator as shown in FIG. **1**. The standard circulator provides little isolation (<1 dB) between the receive channel to transmit channel. The lower curve **153** is the measured isolation using the preferred embodiment of the routing device **50** as shown in FIG. **5**. As shown in FIG. **9**, the receive channel to transmit channel isolation is greater than 25 dB over the 860 MHz to 960 MHz frequency range.

Another embodiment of the present invention makes use of directional couplers in place of the circulators to route the signals to and from the common antenna port through the routing device **50**. FIG. **10** shows the routing device **50** implemented with directional couplers **155** and **156**. The mathematical analysis using directional couplers in place of circulators follows the same derivation as shown in FIG. **6** and FIG. **7**. One of the key differences when using directional couplers in place of circulators is an additional reduction in the received amplitude of the signals as they pass through the directional coupler moving from connecting lines **130** and **132** to connecting lines **140** and **141** respectively as shown on FIG. **10**. Also note that practical directional couplers have undesired leakage paths between the ports **157** to port **159** and port **160** to port **162**. As in the case using circulators, the routing device **50** is capable of canceling the undesired leakage energy at the output port **144** and allowing this energy to be absorbed in the termination **146**.

Another embodiment of the present invention replaces the quadrature hybrids **110**, **111** and **112** in FIG. **5** and FIG. **10** with other types of power division networks as long as the output signals from these devices maintain the amplitude and the relative phase relationships required for proper operation of the routing device **50**. One skilled in the art will recognize in view of this disclosure other types of power dividers that have equal amplitude split with a 90-degree phase difference between the outputs that can be used to practice this invention such as the branchline coupler, overlay coupler, edge-coupled coupler, lumped element coupler and Lange coupler. Likewise, other types of power division networks with equal amplitude but equal phase between the outputs may be employed to practice the present invention. These equal phase dividers include the Wilkinson tee, resistive divider and T-junction or reactive tee. Using one of these equal amplitude-equal phase dividers in place of quadrature hybrid **110**, **111** and/or **112** requires the addition of a 90-degree phase shift network on one side of the divider output.

For example, FIG. **11** shows another embodiment of the routing device **50** using Wilkinson dividers **200**, **201** and **202** in place of the three quadrature hybrids **110**, **112** and **111** respectively as shown on FIG. **5**. To create the required quadrature signal, additional 90-degree phase shifts **203**, **204** and **205** are added to connecting lines **121**, **140**, **132** respectively to create the necessary conditions for isolating the transmit signal from entering the receive channel. The Wilkinson tee divider or any other type of equal phase power divider/combiner in combination with a 90-degree phase shift can also be used within the routing device **50**. The termination **206** is used to absorb the signals that leak or couple through circulators **100** and **101**. Additionally, it is realized that different combinations of divider types can be used in the routing device **50** to provide isolation between the transmit channel and receive channel.

One skilled in the art will understand in light of this disclosure that other types of power divider networks are usable in the practice of this invention that result in a variety of phase differences between the divider's output signals. For example, the ring hybrid, or "rat-race", results in a power division with a 180-phase difference between two of the output ports. Here again, a phase shift network will be required to properly adjust the phase so that signals that leak or couple through the two circulators or directional couplers will be isolated from the receive channel.

The routing device of the present invention may also include amplifiers in the connecting lines to up to the circulators or directional couplers increase the amplitude level of the transmitted signal. These amplifiers should provide approximately an equal amount of amplification to the input signals and approximately an equal amount of phase shift.

The routing device of the present invention may also include modulators in the connecting lines to allow the routing device to operate as a transmit modulator as shown in FIG. **12**. For example, modulators **224** and **225** are placed along connecting lines **121** and **122** respectively. Data signals are applied to the data input ports **226** and **227** and the transmission signals flowing on connecting lines **121** and **122** are modified by the modulators **224** and **225**. The modulators **224** and **225** can be mixers, switches, variable attenuators, variable amplifiers or any device that can modify the amplitude and/or phase of the transmission signal. In the typical operation of an RFID system using backscatter communication, the reader modulation is applied during forward-link transmission from the RFID reader to the RFID tag. During reverse-link communication, the RFID reader transmitter is active but typically not modulated with data during signal reception from the tag to the reader. In this case, the routing device **220** provides isolation between the active transmitter carrier signal and receiver input. The routing device **220** may also include amplifiers in the connecting lines to increase the amplitude level of the transmitted signal to operative levels as shown in FIG. **12**. For example, amplifiers **222** and **223** are placed along connecting lines **121** and **122** respectively.

The routing device of the present invention is optionally operated in full duplex mode with different transmit and receive RF carrier frequencies. In this way, cancellation of the transmit energy at frequency f**1** will be performed by the routing device allowing the receiver to be simultaneously receiving signals at a different frequency f**2**. The only limitation to the frequency spacing between f**1** and f**2** is the operational bandwidth of the circulators, couplers and dividing components used in the routing device.

It will also be appreciated in view of this disclosure that practical limitations in the performance of the divider/combiner **57** may introduce undesired leakage signals that may reduce the transmit to receive isolation of the signal routing device **50**. For example, a transmission leakage signal may exist in the divider/combiner **57** between ports **64** and **65**. A portion of the first divided transmission output signal entering port **64** of the divider/combiner **57** may undesirably leak to port **65** and appear at the output port **53** of the routing device **50**. This leakage is created by but not limited to the isolation of the divider/combiner **57** and reflection introduced at the connection between port **66** of the divider/combiner **57** and connecting line **74**. In the similar way, a portion of the second divided transmission output signal entering port **65** of the divider/combiner **57** may undesirably leak to port **64** and appear at the output port **53** of the routing device **50**. These leakage signals combine into a divider/combiner leakage signal, Ls, appearing at output port **53** of the routing device **50** and may interfere with the proper operation of the receiver. The divider/combiner leakage signal, Ls, is a complex value having an amplitude and relative phase.

It can be shown that when divider/combiner **57** has finite isolation between port **64** and port **65** then the transmit-to-receive isolation of routing device **50** will degrade. In practice, when divider/combiner **57** is a quadrature hybrid, coupled line coupler, branchline coupler, Lange coupler, rat race, ring hybrid or equal phase power combiner such as Wilkinson tee, resistive divider and T-junction or reactive tee, the port-to-port isolation will be in the range of 15-30 dB. The finite isolation creates a transmitter leakage signal that is not cancelled by the routing device **50**. In this case, the divider/combiner leakage signal, Ls, appearing at output port **53** of the routing device **50** is limited by the value of the finite isolation of the divider/combiner **57**.

FIG. **13** shows the signal paths for the leakage signals from port **131** to port **133** and from port **133** to port **131**. The upper and lower sections of the routing device **50** are not shown for clarity. For the transmitted signal entering the signal routing device **50** and divided into the first and second divided transmission signals and routed by the first and second routing devices **100** and **101** to the first and second divided transmission output signals represented in FIG. **13** as S**20** and S**25** respectively and having substantially equal amplitudes and a relative phase shift therebetween. The first and second routing devices **100** and **101** are shown as circulators but can be any other routing device such as directional couplers or other routing device. For this analysis, the first and second divided transmission output signals S**20** and S**25** will be assumed to have a voltage amplitude of 1/sqrt(2) and relative phase difference equal to 90 degrees as listed in TABLE 3. For this analysis, it is assumed that the first and second routing devices **100** and **101** are ideal and signals entering port **123** and **124** are routed to ports **125** and **126** respectively with no change in amplitude and phase shift equal to −ϕ1. Also, signals entering ports **125** and **126** are routed to ports **127** and **128** with no change in amplitude and phase shift equal to −ϕ1. For this analysis, it is further assumed that the connecting lines **130** and **132** will introduce a phase shift of −ϕ4 degrees and that the connecting lines **140** and **141** will introduce a phase shift of −ϕ5 degrees. In practice, these connecting lines will have an associated insertion loss but the insertion loss will not be included as part of this analysis. A portion of second divided transmission output signal S**25** entering port **133** of common hybrid **111** will leak to port **131** as a third transmission leakage signal S**26**. A portion of the first divided transmission output signal S**20** entering port **131** of common hybrid **111** will leak to port **133** as a fourth transmission leakage signal S**21**. These undesired leakage signals are found in practice and not limited to quadrature hybrids. This leakage would also be present in coupled line coupler, branchline coupler, Lange coupler, rat race, ring hybrid or equal phase power combiner such as Wilkinson tee, resistive divider and T-junction or reactive tee. The leakage signal can be measured and/or calculated using standard techniques known in the industry.

For this analysis, the third and fourth transmission leakage signals S**26** and S**21** will experience a change in amplitude equal to H and a phase shift equal to −ϕH. The third and fourth transmission leakage signals S**26** and S**21** will travel along feed lines **130** and **132** respectively and be routed through the signal routing devices **100** and **101** respectively and exit through port **127** and **128** respectively. In practice, these transmission paths will include insertion loss and the amplitude and phase will be a function of frequency. These modified third and fourth transmission leakage signals entering port **142** and port **143** are represented as S**27** and S**22** respectively in FIG. **13** and TABLE 3. The signal S**22** will have an amplitude equal to H/sqrt(2) and relative phase of (−90−2(ϕ1)−2(ϕ4)−ϕ5−ϕH) degrees. The signal S**27** will have amplitude equal to H/sqrt(2) and relative phase of (−2(ϕ1)−2(ϕ4)−ϕ5−ϕH) degrees. The power in each input signal to the output quadrature hybrid **112** is divided in half or the voltage amplitude is scaled by a factor of 1/sqrt(2) in voltage. A relative phase shift of −90 degrees is introduced into the signal passing from the port **143** over to the port **145**. A relative phase shift of −90 degrees is introduced into the signal passing from the port **142** over to the port **144**. A relative phase shift of 0 degrees is introduced into the signal passing from the port **142** over to the port **145**. A relative phase shift of 0 degrees is introduced into the signal passing from the port **143** over to the port **144**.

Vector addition of these leakage signals at port **145** of the quadrature hybrid **112** will show signal cancellation resulting in output amplitude S**24** equal to 0. Vector addition of these leakage signals at port **144** of the quadrature hybrid **112** will show signal addition resulting in output amplitude S**23** equal to H and relative phase shift of (−90−2(ϕ1)−2(ϕ4)−ϕ5−H). Output port **144** is connected to the receiver and the total leakage signal S**23** is undesired and may affect the proper operation of the receiver. The total leakage signal S**23** described here was previously referred to as divider/combiner leakage signal, Ls. Therefore, the divider/combiner leakage signal, Ls, will have a relative amplitude of H and a relative phase shift of (−90−2(ϕ1)−2(ϕ4)−ϕ5−ϕH).

$$Ls=|Ls|\angle\phi_{Ls}=H\angle(-90-2(\phi1)-2(\phi4)-\phi5-\phi H)$$

It is therefore necessary to eliminate or reduce the amplitude of the divider/combiner leakage signal, Ls, to an acceptable level for proper operation of the receiver.

TABLE 3

Signal	Amplitude	Phase
S20	1/sqrt(2)	−90 − ϕ1 − ϕ4
S25	1/sqrt(2)	−ϕ1 − ϕ4
S21	H/sqrt(2)	−90 − ϕ1 − ϕ4 − ϕH
S26	H/sqrt(2)	−ϕ1 − ϕ4 − ϕH
S22	H/sqrt(2)	−90 − 2(ϕ1) − 2(ϕ4) − ϕ5 − ϕH
S27	H/sqrt(2)	−2(ϕ1) − 2(ϕ4) − ϕ5 − ϕH
S24	0	
S23	H	−90 − 2(ϕ1) − 2(ϕ4) − ϕ5 − ϕH

It was previously discussed that tuning elements and/or phase adjustment may be inserted along any connecting line in order to balance the amplitude and phase of the signals traveling within the signal routing device **50**. Unfortunately, tuning elements that "balance" or match signal paths will not reduce the amplitude of the divider/combiner leakage signal, Ls. In contrast to using tuning elements to balance the amplitude and phase characteristics, the present invention optionally provides for the use of reflector devices introduced to the routing device **50** and configured to "imbalance" a portion of the signal paths in order to introduce a compensating signal, Cs, that is substantially equal in amplitude to the divider/combiner leakage signal, Ls, but having approximately 180-degree relative phase difference for the purpose of reducing the amplitude of the divider/combiner leakage signal, Ls, appearing at output port **53** of the routing device **50**. In practice exact matching of Cs and Ls so as to be equal in amplitude and have exactly 180 degree phase difference is impracticable, hence the present invention is directed to an embodiment where this matching is substantially or approximately achieved such that the divider/combiner leakage signal, Ls, is reduced to a level permitting desired system operation such as or better than that illustrated in FIG. **8** isolation characteristic 151. Such reflector devices may include stubs or lumped components or other devices as are known by those skilled in the art.

The present invention further includes embodiments which include a reflector device to create an imbalance in the routing device **50** resulting in a compensation signal, Cs, that will effectively reduce the divider/combiner leakage signal, Ls, created from the finite isolation of the common quadrature hybrid **111**.

As described above and shown in TABLE 3, one of the limitations for achieving high transmit to receive isolation using the signal routing device **50** is the direct result of divider/combiner leakage signal, Ls. In order to reduce the effect of this leakage signal and improve the overall isolation of the signal routing device **50**, a separate compensating signal, Cs, can be added at the receiver port **53**. This additional compensating signal needs to have approximately the same amplitude as the divider/combiner leakage signal, Ls, and approximately 180-degree relative phase shift to the phase of the leakage signal.

The present invention provides for a reflector device **170** or **170'** respectively placed along connecting line **130** or **132** which will introduce an imbalance in routing device **50** and an associated compensating signal, Cs, that appears at the receiver port thus effecting an improvement in transmit to receive isolation when the compensating signal, Cs, is properly set to cancel the divider/combiner leakage signal, Ls. The present invention further provides a configuration wherein both reflector devices **170** and **170'** are used. In configurations when both reflector devices **170** and **170'** are simultaneously used, the combination can be set so they effect an imbalance in routing device **50** and the combined compensation signal, Cs, can also be used to effect a cancellation of the divider/combiner leakage signal, Ls. FIG. **14** shows the signal paths for the signal S**30** reflected from reflector device **170** placed along connecting line **130**. The upper and lower sections of the routing device **50** are not shown for clarity. The reflected signal S**30** is a portion of the first divided transmission output signal leaving port **125** of the routing device **100**. For this analysis, the reflected signal S**30** entering port **125** of the first routing device **100** is assumed to have an amplitude X/sqrt(2) and relative phase (−ϕX−90−2(ϕ6)−ϕ1) degrees, as shown in TABLE 4, where the amplitude of the reflection from reflector device **170** is X and the relative phase of the reflection from reflector device **170** is −ϕX. It is also assumed that signals entering port **125** of signal routing device **100** is routed to port **127** with no change in amplitude and phase shift equal to −ϕ1 degrees. The portion of connecting line **130** between reflector device **170** and port **125** of routing device **100** will introduce a relative phase shift of −ϕ6 degrees. The length of connecting line **140** will introduce an additional phase shift of −ϕ5 degrees. The signal S**31** entering port **142** of output quadrature hybrid **112** will have an amplitude of X/sqrt(2) and relative phase of (−ϕX−90−2(ϕ6)−2(ϕ1)−ϕ5) degrees. The output quadrature hybrid **112** divides the input power to any port in half or the voltage is scaled by a factor of 1/sqrt(2). A relative phase shift of 0 degrees is introduced into the signal passing from the port **142** over to the port **145**. A relative phase shift of −90 degrees is introduced into the signal passing from the port **142** over to the port **144**. The resulting signal S**32** leaving port **145** of output quadrature hybrid **112** will have an amplitude of X/2 and relative phase of (−ϕX−90−2(ϕ6)−2(ϕ1)−ϕ5) degrees. The resulting signal S**33** leaving port **144** of output quadrature hybrid **112** will have an amplitude of X/2 and relative phase of (−ϕX−180−2(ϕ6)−2(ϕ1)−ϕ5) degrees. Reflected signal S**33** was previously referred to as compensating signal, Cs.

$$Cs=|Cs|\angle\phi_{Cs}=(X/2)\angle(-\phi X-180-2(\phi6)-2(\phi1)-\phi5)$$

The reflector device **170** and placement along connecting line **130** is set to provide a compensating signal, Cs, that is substantially equal in the amplitude to the divider/combiner leakage signal, Ls, and relative phase of approximately 180-

degrees out of phase with the divider/combiner leakage signal, Ls. The vector addition of these signals will reduce or eliminate the divider/combiner leakage signal, Ls, thus improving the transmitter to receiver channel isolation.

$$|Cs|\angle\phi_{Cs}\approx|Ls|\angle(\phi_{Ls}-180)$$

for the amplitudes

$$|Cs|\approx|Ls|$$

$$(X/2)\approx H$$

then

$$X\approx(2H)$$

for the phases

$$\angle\phi_{Cs}\approx\angle(\phi_{Ls}-180)$$

$$(-\#X-2(\phi6)-2(\phi1)-\phi5-180)\approx((-90-2(\phi1)-2(\phi4)-\phi5-\phi H)-180)$$

$$(-\phi X-2(\phi6))\approx(-90-2(\phi4)-\phi H)$$

then

$$-\phi X\approx(-90-2(\phi4)-\phi H+2(\phi6))$$

As a result, the amplitude, X, of the reflected signal from reflector device **170** should be set to be substantially equal to twice the amplitude, H, of the leakage signal of common quadrature hybrid **111**. The relative phase, −ϕX, of the reflected signal from reflector device **170** should be set to be approximately equal to the (−90−2(ϕ4)−ϕH+2(ϕ6)) degrees where −ϕH is the phase shift of the leakage signal of common quadrature hybrid **111**.

TABLE 4

Signal	Amplitude	Phase
S30	X/sqrt(2)	−ϕX − 90 − 2(ϕ6) − ϕ1
S31	X/sqrt(2)	−ϕX − 90 − 2(ϕ6) − 2(ϕ1) − ϕ5
S32	X/2	−ϕX − 90 − 2(ϕ6) − 2(ϕ1) − ϕ5
S33	X/2	−ϕX − 180 − 2(ϕ6) − 2(ϕ1) − ϕ5

Reflector device **170** should be set to effect cancellation of the divider/combiner leakage signal, Ls, such that a transmit to receive isolation of at least 30 dB is achieved over a frequency range associated with the system use. More preferably, reflector device **170** should be set to effect leakage cancellation such that at least 35 dB isolation is achieved over the desired frequency range. Still more preferably, reflector device **170** should be set to effect leakage cancellation such that at least 40 dB isolation is achieved over the desired frequency range.

In the preferred embodiment of this invention, reflector device **170** and/or **170'** is an open stub transmission line. FIG. **16**A shows a top view of the preferred embodiment using transmission line **180** that is a portion of one of the connecting lines previously described. Open circuit **182** is at the end of transmission line stub **181**. The length and width of transmission line stub **181** is set to effect cancellation of the divider/combiner leakage signal, Ls. Alternatively, the reflector device **170** and/or **170'** can be a shorted stub transmission line. FIG. **16**B shows a top view of an embodiment using transmission line **180** with a short circuit **184** placed along transmission line stub **183**. The length and width of transmission line stub **183** is set to effect cancellation of the divider/combiner leakage signal, Ls. Alternatively, the reflector device **170** and/or **170'** can a lumped element type reactive component such as a capacitor or inductor. FIG. **16**C shows a top view of an embodiment using transmission line **180** with a short circuit **187** placed at the end of reactive component **186**. It will be understood that FIGS. **16**A-**16**C are not to scale and that they are schematic in nature and that actual implementation is dependent upon the materials and frequencies involved. Reactive component **186** is connected to transmission line stub **185**. The capacitance or inductance value of reactive component **186** and the length and width of transmission line stub **185** are set to effect cancellation of the divider/combiner leakage signal, Ls.

A similar mathematical derivation to that described above can show that a compensating signal reflected from a reflector device **170'** place along connecting line **132** will effect cancellation of the divider/combiner leakage signal, Ls. For this analysis, the reflected signal entering port **126** of the second routing device **101** is assumed to have an amplitude Y/sqrt(2) and relative phase (−ϕY−2(ϕ7)−ϕ1) degrees where the amplitude of the reflection from reflector device **170'** is Y and the relative phase of the reflection from reflector device **170** is −ϕY. It is also assumed that signals entering port **126** of signal routing device **101** is routed to port **128** with no change in amplitude and phase shift equal to −ϕ1 degrees. The portion of connecting line **132** between reflector device **170'** and port **126** of routing device **101** will introduce a relative phase shift of −ϕ7 degrees. The length of connecting line **141** will introduce an additional phase shift of −ϕ5 degrees. The signal entering port **143** of output quadrature hybrid **112** will have an amplitude of Y/sqrt(2) and relative phase of (−ϕY−2(ϕ7)−2(ϕ1)−ϕ5) degrees. The output quadrature hybrid **112** divides the input power to any port in half or the voltage is scaled by a factor of 1/sqrt(2). A relative phase shift of 0 degrees is introduced into the signal passing from the port **143** over to the port **144**. A relative phase shift of −90 degrees is introduced into the signal passing from the port **143** over to the port **145**. The resulting signal leaving port **145** of output quadrature hybrid **112** will have an amplitude of Y/2 and relative phase of (−ϕY−2(ϕ7)−2(ϕ1)−ϕ5−90) degrees. The resulting signal leaving port **144** of output quadrature hybrid **112** will have an amplitude of Y/2 and relative phase of (−ϕY−2(ϕ7)−2(ϕ1)−ϕ5) degrees. This reflected signal was previously referred to as compensating signal, Cs.

As a result, the amplitude, Y, of the reflected signal from reflector device **170'** should be set to be substantially equal to twice the amplitude, H, of the leakage signal of common quadrature hybrid **111**. The relative phase, −ϕY, of the reflected signal from reflector device **170'** should be set to be approximately equal to the (−270−ϕH−2(ϕ4)+2(ϕ7)) degrees where −ϕH is the phase shift of the leakage signal of common quadrature hybrid **111**.

It is important to note that it may be possible to effect cancellation of the divider/combiner leakage signal, Ls, with the introduction of two or more reflector devices placed along connecting line **130** and/or connecting line **132** and therefore effecting an imbalance in the routing device **50** for effecting cancellation of the divider/combiner leakage signal, Ls.

Another technique for reducing the amplitude of divider/combiner leakage signal, Ls, is provided by reflector device **171** placed along connecting line **137** between common port **134** of the common quadrature hybrid **111** and the common port **52** of the signal routing device **50** as shown in FIG. **15**. Portions of the upper and the lower sections of routing device **50** in FIG. **15** are not shown for clarity. Reflector device **171** reflects a portion of the transmission output signal back into common port **134** of common quadrature hybrid **111**. A substantial portion of this reflected signal will appear at port **144** of output quadrature hybrid **112** and may be used to reduce the amplitude of divider/combiner leakage signal, Ls. Reflector device **171** is set to effect an amplitude for the compensating signal, Cs', appearing at port **144**, to be substantially equal in amplitude to the divider/combiner leakage signal, Ls, appearing at port **144**, and approximately 180-degrees in relative phase to the divider/combiner leakage signal, Ls, appearing at port **144**. For this configuration, the compensating signal will be referred with variable Cs'. The vector addition of divider/combiner leakage signal, Ls, and the compensating signal, Cs', created from signal reflection from the reflector device **171** will result in signal cancellation at port **144** and improve the transmitter to receiver channel isolation. FIG. **15** shows the signal path from the reflector device **171** to port **144** of the output quadrature hybrid **112**. TABLE 5 shows the amplitude and relative phase for the associated signals. For this analysis, it is assumed that signals entering port **125** and **126** of signal routing device **100** and **101** are routed to ports **127** and **128** respectively with no change in amplitude and phase shift equal to −ϕ1. The portion of connecting line **137** between reflector device **171** and common port **134** of common quadrature hybrid **111** will introduce a relative phase shift of −ϕ8 degrees. The signal S**34** is the reflected signal from the reflector device **171** and enters common port **134** of common quadrature hybrid **111**. For this analysis, the reflected signal S**34** is assumed to have an amplitude R and relative phase (−ϕR−ϕ1−ϕ4−2(ϕ8)−90) where the amplitude of the reflection from reflector device **171** is R and the relative phase of the reflection from reflector device **171** is −ϕR. The signal S**34** enters common quadrature hybrid **111** at port **134** and divided between port **131** and port **133**. The signal S**35** leaving port **131** will have an amplitude equal to R/sqrt(2) and relative phase of (−ϕR−ϕ1−ϕ4−2(ϕ8)−90) degrees. The signal S**36** leaving port **133** will have an amplitude equal to R/sqrt(2) and relative phase of (−ϕR−ϕ1−ϕ4−2(ϕ8)−180) degrees. The connecting lines **130** and **132** will introduce an additional phase shift of −ϕ4 degrees to each respective signal. The signal routing device **100** and **101** will introduce a relative phase shift of −ϕ1 degrees. The connecting lines **140** and **141** will introduce a phase shift of −ϕ5 degrees to each respective signal. The signal S**37** entering port **142** of output quadrature hybrid **112** will have a magnitude of R/sqrt(2) and relative phase of (−ϕR−2(ϕ1)−2(ϕ4)−2(ϕ8)−90−ϕ5) degrees. The signal S**38** entering port **143** of output quadrature hybrid **112** will have an amplitude of R/sqrt(2) and relative phase of (−ϕR−2(ϕ1)−2(ϕ4)−2(ϕ8)−180−ϕ5) degrees. The power in each input signal to the output quadrature hybrid **112** is divided in half or the voltage is scaled by a factor of 1/sqrt(2). A relative phase shift of −90 degrees is introduced into the signal passing from the port **143** over to the port **145**. A relative phase shift of −90 degrees is introduced into the signal passing from the port **142** over to the port **144**. A relative phase shift of 0 degrees is introduced into the signal passing from the port **142** over to the port **145**. A relative phase shift of 0 degrees is introduced into the signal passing from the port **143** over to the port **144**.

Vector addition of the reflected signals at port **145** of the output quadrature hybrid **112** will show signal cancellation resulting in a signal amplitude of signal S**39** equal to 0. Vector addition of the reflected signals at port **144** of the output quadrature hybrid **112** will show signal addition resulting in output amplitude of signal S**40** equal to R and relative phase (−ϕR−2(ϕ1)−2(ϕ4)−2(ϕ8)−180−ϕ5) degrees. Reflected signal S**40** is referred to as the compensating signal, Cs'.

$$Cs'=|Cs'|\angle\phi_{Cs'}=R\angle(-\phi R-2(\phi1)-2(\phi4)-2(\phi8)-180-\phi5)$$

The reflector device **171** and placement along connecting line **137** is set to provide a compensating signal, Cs', that is substantially equal in the amplitude to the divider/combiner leakage signal, Ls, and relative phase of approximately 180-degrees with the divider/combiner leakage signal, Ls. The vector addition of these signals will reduce or eliminate the amplitude of the divider/combiner leakage signal, Ls, thus improving the transmitter to receiver channel isolation.

$$|Cs'|\angle\phi_{Cs}\approx|Ls|\angle(\phi_{Ls}-180)$$

for the amplitudes

$$|Cs'|\approx|Ls|$$

then

$$R\approx H$$

for the phase,

$$\angle\phi_{Cs}\approx\angle(\phi_{Ls}-180)$$

$$(-\phi R-2(\phi1)-2(\phi4)-2(\phi8)-180-\phi5)\approx((-90-2(\phi1)-2(\phi4)-\phi5-\phi H)-180)$$

then

$$-\phi R\approx-\phi H-90+2(\phi8)$$

As a result, the amplitude, R, of the reflected signal from reflector device **171** should be set to be substantially equal the amplitude, H, of the leakage signal of common quadrature hybrid **111**. The relative phase, −ϕR, of the reflected signal from reflector device **171** should be set to be approximately equal to the (−ϕH−90+2(ϕ8)) degrees where −ϕH is the phase shift of the leakage signal of common quadrature hybrid **111**. The relative phase is a modulo function of 360-degrees so that the relative phase, −ϕR, of the reflected signal from reflector device **171** can also be set to be approximately equal to the (−ϕH−90+2(ϕ8)−n(360)) degrees, where n= . . . , −2, −1, 0, 1, 2, 3, 4, ... Reflector device **171** should be set to effect cancellation of the divider/combiner leakage signal, Ls, such that a transmit to receive isolation of at least 30 dB is achieved over a frequency range associated with the system use. More preferably, reflector device **171** should be set to effect leakage cancellation such that at least 35 dB isolation is achieved over the desired frequency range. Still more preferably, reflector device **171** should be set to effect leakage cancellation such that at least 40 dB isolation is achieved over the desired frequency range.

In the preferred embodiment of this invention, reflector device **171** is an open stub transmission line. FIG. **16**A shows a top view of the preferred embodiment using transmission line **180** that is a portion of one of the connecting lines previously described. Open circuit **182** is at the end of transmission line stub **181**. The length and width of transmission line stub **181** is set to effect cancellation of the divider/combiner leakage signal, Ls. Alternatively, the reflector device **171** can be a shorted stub transmission line. FIG. **16**B shows a top view of an embodiment using transmission line **180** with a short circuit **184** placed along transmission line stub **183**. The length and width of transmission line stub **183** is set to effect cancellation of the divider/combiner leakage signal, Ls. Alternatively, the reflector device **171** can a lumped element type reactive component such as a capacitor or inductor. FIG. **16**C shows a top view of an embodiment using transmission line **180** with a short circuit **187** placed at the end of reactive component **186**. Reactive component **186** is connected to transmission line stub **185**. The capacitance or inductance value of reactive component **186** and the length and width of transmission line stub **185** are set to effect cancellation of the divider/combiner leakage signal, Ls.

TABLE 5

Signal	Amplitude	Phase
S34	R	$-\phi R - \phi 1 - \phi 4 - 2(\phi 8) - 90$
S35	R/sqrt(2)	$-\phi R - \phi 1 - \phi 4 - 2(\phi 8) - 90$
S36	R/sqrt(2)	$-\phi R - \phi 1 - \phi 4 - 2(\phi 8) - 180$
S37	R/sqrt(2)	$-\phi R - 2(\phi 1) - 2(\phi 4) - 2(\phi 8) - 90 - \phi 5$
S38	R/sqrt(2)	$-\phi R - 2(\phi 1) - 2(\phi 4) - 2(\phi 8) - 180 - \phi 5$
S39	0	
S40	R	$-\phi R - 2(\phi 1) - 2(\phi 4) - 2(\phi 8) - 180 - \phi 5$

It will be appreciated that a reflector device introduced to create a compensating signal, Cs or Cs', to effect cancellation of the amplitude of the divider/combiner leakage signal, Ls, can also be implemented in routing device **50** when directional couplers **155** and **156** are used in place of circulators **100** and **101**. As shown in FIG. **10**, leakage from common quadrature hybrid **111** is still present in this configuration and any divider/combiner leakage signal found on connecting line **147** can be cancelled through the use of a reflector device placed on connecting line **137** and/or connecting line **130** and/or connecting line **132**.

Having described preferred embodiments of the invention with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the invention as defined in the appended claims. Such modifications include substitution of components for components specifically identified herein, wherein the substitute component provide functional results which permit the overall functional operation of the present invention to be maintained. Such substitutions are intended to encompass presently known components and components yet to be developed which are accepted as replacements for components identified herein and which produce result compatible with operation of the present invention. Furthermore, while examples have been provided illustrating operation at certain power levels and frequencies, the present invention as defined in this disclosure and claims appended hereto is not considered limited to frequencies and power levels recited herein. It is furthermore to be understood that the receiver and transmitter referenced herein is not considered limited to any particular types of receivers or transmitters nor any particular form of signals in that the signals may carry analog or digital information, in any modulation scheme, or the signals need not carry information. Furthermore, the signals used in this invention are considered to encompass any electromagnetic wave transmission.

What is claimed is:

1. An electromagnetic signal routing assembly for effecting two way duplex transmissions, comprising:

a transmission signal input for receiving first transmission signal;

a common port for outputting a portion of said first transmission signal from said transmission signal input and simultaneously receiving a second transmission signal;

a transmission signal output for outputting a portion of said second transmission signal;

a signal divider receiving said first transmission signal from said transmission signal input and dividing said first transmission signal into first and second divided transmission signals having amplitudes within a first amplitude range of each other and a first relative phase shift therebetween;

first and second routing devices each having at least first, second and third ports, said first and second routing devices being configured to simultaneously deliver a signal at said first port to said second port and another signal at said second port to said third port, wherein:

s21 is a transmission coefficient from said first port to said second port;

s32 is a transmission coefficient from said second port to said third;

s31 is a transmission coefficient from said first port to said third port;

said s21 is greater than said s31; and

said s32 is greater than said s31;

said first routing device having said first divided transmission signal applied to said first port of said first routing device and simultaneously producing:

a first divided transmission output signal at said second port of said first routing device; and

a first transmission leakage signal at said third port of said first routing device,

each resultant from said first divided transmission signal;

said first routing device also having a third divided transmission signal, when present, applied to said second port of said first routing device and producing, simultaneously with said first divided transmission output signal and said first transmission leakage signal, a third divided transmission output signal at said third port of said first routing device resultant from said third divided transmission signal;

said second routing device having said second divided transmission signal applied to said first port of said second routing device and simultaneously producing:

a second divided transmission output signal at said second port of said second routing device; and

a second transmission leakage signal at said third port of said second routing device,

each resultant from said second divided transmission signal;

said second routing device also having a fourth divided transmission signal, when present, applied to said second port of said second routing device and producing, simultaneously with said second divided transmission output signal and said second transmission leakage signal, a fourth divided transmission output signal at said third pert of said second routing device resultant from said fourth divided transmission signal:

a signal divider/combiner having:

first and second divider/combiner ports for receiving said first and second divided transmission output signals and a configuration for combining these signals at levels within a second relative amplitude range and with a second relative phase shift therebetween to output said portion of said first transmission signal to said common port; and

said configuration being such that said second transmission signal, when present and received at said common port, said second transmission signal is divided into said third and fourth divided transmission signals having amplitudes within said second relative amplitude range and with said second relative phase shift therebetween;

a signal combiner having first and second combiner inputs for receiving said first and second transmission leakage signals and, when present, for receiving said third and fourth divided transmission output signals, said signal combiner including said transmission signal output, and said signal combiner being configured to introduce a third relative phase shift into signals applied to at least one of said first and second combiner inputs and combine signals applied to said first and second combiner inputs at said transmission signal output at levels within a third amplitude range such that:

said first and second transmission leakage signals arrive at said transmission signal output at levels within an amplitude tolerance range and a total relative phase shift therebetween within a phase tolerance range situated about 180 degrees to effect a destructive combination resulting in at least partial cancellation of said first and second transmission leakage signals at said transmission signal output; and

said third and fourth divided transmission output signals, when present, arrive at said transmission signal output to effect a constructive combination of said third and fourth divided transmission output signals to output a portion of said second transmission signal at said transmission signal output; said configuration of said signal divider/combiner producing:

a third transmission leakage signal, at said first divider/combiner port which is a portion of said second divided transmission output signal; and

a fourth transmission leakage signal, at said second divider/combiner port, which is a portion of said first divided transmission output signal;

said first routing device receiving said third transmission leakage signal at said second port and producing at said third port a third transmission leakage output signal resultant from said third transmission leakage signal;

said second routing device receiving said fourth transmission leakage signal at said second port and producing at said third port a fourth transmission leakage output signal resultant from said forth transmission leakage signal;

a reflecting configuration configured to produce at least one reflected signal, said reflecting configuration being one of:

a first reflector configuration having a reflector device applied to said common port and configured to reflect into said common port a portion of said portion of said first transmission signal as a common port reflected signal, and said configuration of said signal divider/combiner being so arranged as to divide said common port reflected signal into first and second reflected divided signals having amplitude levels within said second amplitude range and said second relative phase shift therebetween, said first and second reflected divided signals being respectively output at said first and second divider/combiner ports as said at least one reflected signal;

a second reflector configuration having a reflector device applied between said second port of said first routing device and said first divider/combiner port of said signal divider/combiner and configured to reflect into said second port of said first routing device a reflected signal, which is a portion of said first divided transmission output signal, as said at least one reflected signal thereby creating an imbalance in levels of said first divided transmission output signal and said second divided transmission output signal arriving at said first and second divider/combiner ports;

a third reflector configuration having a reflector device applied between said second port of said second routing device and said second divider/combiner port of said signal divider/combiner and configured to reflect into said second port of said second routing device a reflected signal, which is a portion of said second divided transmission output signal, as said at least one reflected signal thereby creating an imbalance in levels of said first divided transmission output signal and said second divided transmission output signal arriving at said first and second divider/combiner ports; or

a fourth reflector configuration having:

a first reflector device applied between said second port of said first routing device and said first divider/combiner port of said signal divider/combiner and configured to have a first reflection coefficient to reflect into said second port of said first routing device a portion of said first divided transmission output signal as a first reflected signal; and

a second reflector device applied between said second port of said second routing device and said second divider/combiner port of said signal divider/combiner and configured to have a second reflection coefficient to reflect into said second port of said second routing device a portion of said second divided transmission output signal as a second reflected signal, wherein said first and second reflection coefficients are such that a phase imbalance is generated between said first reflected signal and said second reflected signal, and said at least one reflected signal includes said first reflected signal and said second reflected signal; and

said signal combiner having said first and second combiner inputs respectively receiving said third and fourth transmission leakage output signals, and respectively receiving, via at least one of said first and second routing devices, at least one reflection signal output resultant from said at least one reflected signal, said signal combiner being so configured as to destructively combine said at least one reflection signal output at said transmission signal output with said third and fourth transmission leakage output signals to effect at least partial cancellation of said third and fourth transmission leakage output signals arriving at said transmission signal output.

2. The electromagnetic signal routing assembly or claim **1** wherein said first and second routing devices are circulators.

3. The electromagnetic signal routing assembly of claim **2** wherein said signal divider is a quadrature hybrid introducing said first relative phase shift and having an input port receiving said first transmission signal, an isolated port with a termination applied thereto, said first and second divided transmission signals are output at first and second divider outputs of said quadrature hybrid, said first relative phase shift is such that said first divided transmission signal lags said second divided transmission signal by said first relative phase shift.

4. The electromagnetic signal routing assembly of claim **3** wherein said signal divider/combiner is a quadrature hybrid introducing said second relative phase shift and having an isolated port with a termination applied thereto, two ports for receiving said first and second divided transmission output signals, said second relative phase shift introduced into said second divided transmission output signal is such that said second divided transmission output signal lags said first divided transmission output signal by said second relative phase shift such that:

said first and second divided transmission output signals are constructively combined at said common port to output said portion of the first transmission signal; and

said second transmission signal, when present, and simultaneously received at said common port is divided into said third and fourth divided transmission signals having said second relative phase shift, and said fourth divided transmission signal lags said third divided transmission signal by said second relative phase shift.

5. The electromagnetic signal routine assembly of claim **4** wherein said signal combiner is a quadrature hybrid having an isolated port with a termination applied thereto, two ports for receiving said first and second transmission leakage signals, said first transmission leakage signal lags said second transmission leakage signal by said third relative phase shift, and said first and second leakage transmission signals are combined at said isolated port and dissipated in said termination.

6. The electromagnetic signal routing assembly of claim **2** wherein said portion of said first transmission signal delivered to said common port is in a range of 0.3 dB to 2.5 dB lower than an amplitude level of said first transmission signal at said transmission signal input.

7. The electromagnetic signal routing assembly of claim **6** wherein said portion of said second transmission signal delivered to said transmission signal output is in a range of 0.3 dB to 2.5 dB lower than an amplitude level of said second transmission signal delivered to said common port.

8. The electromagnetic signal routing assembly of claim **2** wherein said at least partial cancellation of said first and second transmission leakage signals at said transmission signal output results in a combined signal that is at least 27 dB attenuated relative to said first transmission signal.

9. The electromagnetic signal routing assembly of claim **2** wherein said at least partial cancellation of said first and second transmission leakage signals at said transmission signal output results in a combined signal that is at least 37 dB attenuated relative to said first transmission signal.

10. The electromagnetic signal routing assembly of claim **1** wherein said signal divider/combiner is a quadrature hybrid introducing said second relative phase shift and having an isolated port with a termination applied thereto, two ports for receiving said first and second divided transmission output signals, said second relative phase shift introduced into said second divided transmission output signal is such that said second divided transmission output signal lags said first divided transmission output signal by said second relative phase shift such that:

said first and second divided transmission output signals are constructively combined at said common port to output said portion of the first transmission signal; and

said second transmission signal, when present, and simultaneously received at said common port is divided into said third and fourth divided transmission signals having said second relative phase shift, and said fourth divided transmission signal lags said third divided transmission signal by said second relative phase shift.

11. The electromagnetic signal routing assembly of claim **1** wherein said signal combiner is a quadrature hybrid having an isolated port with a termination applied thereto, two ports for receiving said first and second transmission leakage signals, said first transmission leakage signal lags said second transmission leakage signal by said third relative phase shift, and said first and second leakage transmission signals are combined at said isolated port and dissipated in said termination.

12. The electromagnetic signal routing assembly of claim **1** wherein said signal divider is a power splitter device having an input port receiving said transmission signal, and two output branches delivering said first and second divided transmission signals, one of said two output branches includes a phase shifting element introducing said first relative phase shift.

13. The electromagnetic signal routing assembly of claim **1** wherein:

said signal divider/combiner is a power splitter/combiner device having two branches for respectively receiving said first and second divided transmission signals, said power splitter/combiner device is configured as a signal combiner and one of said two branches includes a phase shifting element introducing said second relative phase shift; and

said power splitter/combiner device simultaneously divides said second transmission signal, when present, from said common port into said third and fourth divided transmission signals.

14. The electromagnetic signal routing assembly of claim **1** wherein said signal combiner is a power combiner having two input branches and an output port, one of said two input branches includes a phase shifting element introducing said third relative phase shift, said power combiner being configured for simultaneously receiving:

said first and second transmission leakage signals to effect destructive combining thereof at the output port; and

said third and fourth divided transmission output signals, when present, to combine at the output port.

15. The electromagnetic signal routing assembly of claim **1** wherein said first and second divided transmission signals are amplified.

16. The electromagnetic signal routing assembly for effecting two way duplex transmissions according to claim **1**, wherein:

said reflecting configuration is said first reflector configuration;

said first routing device receives said first reflected divided signal at said second port and produces, simultaneously at said third port a first reflected divided output signal and said third transmission leakage output signal respectively resultant from said first reflected divided signal and said third transmission leakage signal;

said second routing device receives said second reflected divided signal at said second port and produces, simultaneously at said third port a second reflected divided output signal and said fourth transmission leakage output signal respectively resultant from said second reflected divided signal and said fourth transmission leakages signal;

and

said signal combiner has said first and second combiner inputs respectively receiving said third and fourth transmission leakage output signals, and respectively receiving said first and second reflected divided output signals as said at least one reflection signal output, said signal combiner is so configured as to destructively combine said first and second reflected divided output signals at said transmission signal output with said third and fourth transmission leakage output signals to effect said at least partial cancellation of said third and fourth transmission leakage output signals arriving at said transmission signal output.

17. The electromagnetic signal routing assembly of claim **16** wherein:

said third transmission leakage signal has an amplitude equal to an amplitude of said second divided transmission output signal multiplied by H and a phase shift $-\phi H$ relative to said second divided transmission output signal;

said fourth transmission leakage signal has an amplitude equal to an amplitude of said first divided transmission output signal multiplied by H and a phase shift $-\phi H$ relative to said first divided transmission output signal; and

said configuration of said reflector device is set to have a reflection coefficient R and a relative phase $-\phi R$ so as to effect said destructive combination of said third and fourth transmission leakage output signals by having R set to within an amplitude range of H and $-\phi R$ set to within a reflected phase range of $(-\phi H-90-2(\phi 8))$ such that said at least partial cancellation of said third and fourth transmission leakage output signals and said at least partial cancellation of said first and second transmission leakage signals produces a transmit to receive isolation of at least 30 dB, wherein:

$\phi 8$ is a net electrical length of a portion of the common connecting line between said reflecting device and said common port of said signal divider/combiner.

18. The electromagnetic signal routing assembly of claim **16** wherein said reflector device is an open stub.

19. The electromagnetic signal routing assembly of claim **16** wherein said reflector device is a shorted stub.

20. The electromagnetic signal routing assembly of claim **16** wherein said reflector device includes a reactive component selected from the group consisting of a capacitor and an inductor.

21. The electromagnetic signal routing assembly for effecting two way duplex transmissions according to claim **1**, wherein:

said reflecting configuration is said second reflector configuration:

said first routing device receives said reflected signal and said third transmission leakage signal at said second port and produces, simultaneously at said third port a reflected output signal and said third transmission leakage output signal respectively resultant from said reflected signal and said third transmission leakage signal;

and

said signal combiner has said first and second combiner inputs respectively receiving said third and fourth transmission leakage output signals, and said first combiner input receiving said reflected output signal as said at least one reflection signal output, said signal combiner is so configured as to destructively combine a portion of said reflected output signal at said transmission signal output with said third and fourth transmission leakage output signals to effect said at least partial cancellation of said third and fourth transmission leakage output signals at said transmission signal output.

22. The electromagnetic signal routing assembly of claim **21** wherein:

said third transmission leakage signal has an amplitude equal to an amplitude of said second divided transmission output signal multiplied by H and a phase shift $-\phi H$ relative to said second divided transmission output signal; and

said fourth transmission leakage has an amplitude equal to an amplitude of said first divided transmission output signal multiplied by H and a phase shift $-\phi H$ relative to said first divided transmission output signal;

said reflected signal has an amplitude equal to an amplitude of said first divided transmission output signal multiplied by X and relative phase shift $-\phi X$;

X is set to within a reflected amplitude range of 2H and $-\phi X$ is set to within a reflected phase range of $(-90-2(\phi 4)-\phi H-2(\phi 6)$ such that said at least partial cancellation of said third and fourth transmission leakage output signals and said at least partial cancellation of said first and second transmission leakage signals produces a transmit to receive isolation of at least 30 dB, wherein:

$\phi 4$ is a net electrical length of a first connecting line connecting the second port of the first routing device to the first divider/combiner port;

$\phi 4$ is a not electrical length of a second connecting line connecting the second port of the second routing device to the second divider/combiner port; and

$\phi 6$ is a net electrical length of a portion of the first connecting line between said reflecting device and said second port of said first routing device.

23. The electromagnetic signal routing assembly of claim **21** wherein said reflector device is an open stub.

24. The electromagnetic signal routing assembly acclaim **21** wherein said reflector device is a shorted stub.

25. The electromagnetic signal routing assembly of claim **21** wherein said reflector device includes a reactive component selected from the group consisting of a capacitor and an inductor.

26. The electromagnetic signal routing assembly for effecting two way duplex transmissions according to claim **1**, wherein:

said reflecting configuration is said third reflector configuration;

said second routing device receives said reflected signal and said fourth transmission leakage signal at said second port and produces simultaneously at said third port a reflected output signal and said fourth transmission leakage output signal respectively resultant from said reflected signal and said fourth transmission leakage signal; and

said signal combiner has said first and second combiner inputs respectively receiving said third and fourth transmission leakage output signals, and said second combiner input receiving said reflected output signal as said at least one reflection signal output, said signal combiner is so configured as to destructively, combine a portion of said reflected output signal at said transmission signal output with said third and fourth transmission leakage output signals to effect said at least partial cancellation of said third and fourth transmission leakage output signals at said transmission signal output.

27. The electromagnetic signal routing assembly of claim **26** wherein:

said third transmission leakage signal has art amplitude equal to an amplitude of said second divided transmission output signal multiplied by and a phase shift $-\phi H$ relative to said second divided transmission output signal; and

said fourth transmission leakage signal has an amplitude equal to an amplitude of said first divided transmission output signal multiplied by H and a phase shift $-\phi H$ relative to said first divided transmission output signal;

said reflected signal has an amplitude equal to an amplitude of said second divided transmission output signal multiplied by Y and a relative phase shift of $-\phi Y$; and

Y is set to within a reflected amplitude range of 2H and $-\phi Y$ is set to within a reflected phase range of $(-270-2(\phi 4)-\phi H+2(\phi 7))$ such that sat at least partial cancellation of said third and fourth leakage signals and said at least partial cancellation of said first and second leakage signals produces a transmit to receive isolation of at least 30 dB, wherein:

$\phi 4$ is a net electrical length of a first connecting line connecting the second port of the first routing device to the first divider/combiner port;

$\phi 4$ is a net electrical length of a second connecting line connecting the second port of the second routing device to the second divider/combiner port; and

ϕ7 is a net electrical length of a portion of the second connecting line between said reflecting device and said second port of said second routing device.

28. The electromagnetic signal routing assembly of claim **26** wherein said reflector device is an open stub.

29. The electromagnetic signal routing assembly of claim **26** wherein said reflector device is a shorted stub.

30. The electromagnetic signal routing assembly of claim **26** wherein said reflector device includes a reactive component selected from the group consisting of a capacitor and an inductor.

31. The electromagnetic signal routing assembly for effecting two way duplex transmissions according to claim **1**, wherein:

said reflecting configuration is said fourth reflector configuration;

said first routing device receives said first reflected signal and said third transmission leakage signal at said second port and produces, simultaneously at said third port a first reflected output signal and said third transmission leakage output signal;

said second routing device receives said second reflected signal and said fourth transmission leakage signal at said second port and produces, simultaneously at said third port a second reflected output signal and said fourth transmission leakage output signal; and

said signal combiner has said first and second combiner inputs respectively receiving said third and fourth transmission leakage output signals, and said first and second combiner inputs respectively receiving said first and second reflected output signals as said at least one reflection signal output, said signal combiner being so configured as to destructively combine a portion of said first and second reflected output signals at said transmission signal output with said third and fourth transmission leakage output signals to effect said at least partial cancellation of said third and fourth transmission leakage output signals at said transmission signal output such that said at least partial cancellation of said third and fourth leakage signals and said at least partial cancellation of said first and second leakage signal produces a transmit to receive isolation of at least 30 dB.

32. The electromagnetic signal routing assembly of claim **31** wherein said first and second reflector devices are embodied as one of an open stub, a shorted stub, or a reactive component selected from the group consisting of a capacitor and an inductor.

33. The electromagnetic signal routing assembly of claim **1** wherein said first and second transmission leakage signals are respectively attenuated 10 dB or greater relative to said first and second divided transmission signals, wherein said first amplitude range, said first relative phase shift, said third amplitude range, and said third relative phase shift are such that said first and second transmission leakage signals arrive at said transmission signal output with said total relative phase shift equal to 180 degrees within said phase tolerance range, wherein said phase tolerance range is +/−20.5 degrees, and having amplitudes within said amplitude tolerance range, wherein said amplitude tolerance range is +3.8 dB to −1.6 dB, so that said destructive combination results in said first and second leakage signals destructively combining at said transmission signal output to have an combined amplitude attenuated by said at least partial cancellation which is at least 22 dB relative to said first transmission signal.

34. The electromagnetic signal routing assembly of claim **33** wherein said phase tolerance range is +/−10 degrees, said amplitude tolerance range is +1.2 dB to −0.8 dB, and said reflector configuration effects said at least partial cancellation of said third and fourth transmission leakage output signals such that a transmit to receive isolation between said transmission signal input and said transmission signal output is at least 30 dB.

35. The electromagnetic signal routing assembly of claim **34** wherein said phase tolerance range is +/−5 degrees, said amplitude tolerance range is +/−0.3 dB, and said reflector configuration effects said at least partial cancellation of said third and fourth transmission leakage output signals such that a transmit to receive isolation between said transmission signal input and said transmission signal output is at least 35 dB.

36. The electromagnetic signal routing assembly of claim **1** wherein said first and second routing devices are directional couplers.

37. The electromagnetic signal routing assembly of claim **1** wherein said first and second routing devices are duplexing filters.

38. An electromagnetic signal routing assembly for effecting two way duplex transmissions comprising:

a transmission signal input for receiving first transmission signal;

a common port for outputting a portion of said first transmission signal from said transmission signal input and simultaneously receiving a second transmission signal;

a transmission outputting a portion of said second transmission signal;

a signal divider receiving said first transmission signal from said transmission signal input and dividing said first transmission signal into first and second divided transmission signals having amplitudes within a first amplitude range of each other and a first relative phase shift therebetween;

first and second routing devices each having at least first, second and third ports, said first and second routing device being configured to simultaneously deliver a signal at said first port to said second port and another signal at said second port to said third port, wherein:

s21 is a transmission coefficient from said first port to said second port;

s32 is a transmission coefficient from said second port to said third;

s31 is a transmission coefficient from said first port to said third port;

said s21 is greater than said s31; and

said s32 is greater than said s1;

said first and second routing devices are each a directional coupler;

said first routing device having said first divided transmission signal applied to said first port of said first routing device and simultaneously producing:

a first divided transmission output signal at said second port of said first routing device; and

a first transmission leakage signal at said third port of said first routing device,

each resultant from said first divided transmission signal;

said first routine device also having a third divided transmission signal, when present, applied to said second port of said first routing device and producing, simultaneously with said first divided transmission output signal and said first transmission leakage signal, a third divided transmission output signal at said third port of said first routing device resultant from said third divided transmission signal;

said second routing device having said second divided transmission signal applied to said first port of said second routing device and simultaneously producing:

a second divided transmission output signal at said second port of said second routing device; and

a second transmission leakage signal at said third port of said second routing device,

each resultant from said second divided transmission signal;

said second routing device also having a fourth divided transmission signal, when present, applied to said second port of said second routing device and producing, simultaneously with said second divided transmission output signal and said second transmission leakage signal, a fourth divided transmission output signal at said third port of said second routing device resultant from said fourth divided transmission signal;

a signal divider/combiner having:

first and second divider/combiner ports for receiving said first and second divided transmission output signals and a configuration for combining these signals at levels within a second relative amplitude range and with a second relative phase shift therebetween to output said portion of said first transmission signal to said common port; and

said configuration being such that said second transmission signal, when present and received at said common port, said second transmission signal is divided into said third and fourth divided transmission signals having amplitudes within said second relative amplitude range and with said second relative phase shift therebetween; and

a signal combiner having first and second combiner inputs for receiving said first and second transmission leakage signals and, when present, for receiving said third and fourth divided transmission output signals, said signal combiner including said transmission signal output, and said signal combiner being configured to introduce a third relative phase shift into signals applied to at least one of said first and second combiner inputs and combine signals applied to said first and second combiner inputs at said transmission signal output at levels within a third amplitude range such that:

said first and second transmission leakage signals arrive at said transmission signal output at levels within an amplitude tolerance range and a total relative phase shift therebetween within a phase tolerance range situated about 180 degrees to effect a destructive combination resulting in at least partial cancellation of said first and second transmission leakage signals at said transmission signal output; and

said third and fourth divided transmission output signals, when present, arrive at said transmission signal output to effect a constructive combination of said third and fourth divided transmission output signals to output a portion of said second transmission signal at said transmission signal output.

39. The electromagnetic signal routing assembly of claim **38** wherein said signal divider is a quadrature hybrid introducing said first relative phase shift and having an input port receiving said first transmission signal, an isolated port with a termination applied thereto, said first and second divided transmission signals are output at first and second divider outputs of said quadrature hybrid, said first relative phase shift is such that said first divided transmission signal lags said second divided transmission signal by said first relative phase shift.

40. The electromagnetic signal routing assembly of claim **39** wherein said signal divider/combiner is a quadrature hybrid introducing said second relative phase shift and having an isolated port with a termination applied thereto, two ports for receiving said first and second divided transmission output signals, said second relative phase shift introduced into said second divided transmission output signal is such that said second divided transmission output signal lags said first divided transmission output signal by said second relative phase shift such that:

said first and second divided transmission output signals are constructively combined at said common port to output said portion of the first transmission signal; and

said second transmission signal, when present, and simultaneously received at said common port is divided into said third and fourth divided transmission signals having said second relative phase shift, and said fourth divided transmission signal lags said third divided transmission signal by said second relative phase shift.

41. The electromagnetic signal routing assembly of claim **40** wherein said signal combiner is a quadrature hybrid having an isolated port with a termination applied thereto, two ports for receiving said first and second transmission leakage signals, said first transmission leakage signal lags said second transmission leakage signal by said third relative phase shift, and said first and second leakage transmission signals are combined at said isolated port and dissipated in said termination.

42. The electromagnetic signal routing assembly of claim **38** wherein said portion of said first transmission signal delivered to said common port is in a range of 0.2 dB to 4.0 dB lower than an amplitude level of said first transmission signal at said transmission signal input.

43. The electromagnetic signal routing assembly of claim **42** wherein said portion of said second transmission signal delivered to said transmission signal output is in a range of 6.0 dB to 40.0 dB lower than an amplitude level of said second transmission signal delivered at said common port.

44. An electromagnetic signal routing assembly for effecting two way duplex transmissions, comprising:

a transmission signal input for receiving first transmission signal;

a common port for outputting a portion of said first transmission signal from said transmission signal input and simultaneously receiving a second transmission signal;

a transmission signal output for outputting a portion of said second transmission signal;

a signal divider receiving said first transmission signal from said transmission signal input and dividing said first transmission signal into first and second divided transmission signals having amplitudes within a first amplitude range of each other find a first relative phase shift therebetween;

first and second routing devices each having at least first, second and third ports, said first and second routing devices being configured to simultaneously deliver a signal at said first port to said second port and another signal at said second port to said third port, wherein:

s21 is a transmission coefficient from said first port to said second port;

s32 is a transmission coefficient from said second port to said third;

s31 is a transmission coefficient from said first port to said third port;

said s21 is greater than said s31; and

said s32 is greater than said s31;

said first routing device having said first divided transmission signal applied to said first port of said first routing device and simultaneously producing:

a first divided transmission output signal at said second port of said first routing device; and a first transmission leakage signal at said third port of said first routing device, each resultant from said first divided transmission signal;

said first routing device also having a third divided transmission signal, when present, applied to said second port of said first routing device and producing, simultaneously with said first divided transmission output signal and said first transmission leakage signal, a third divided transmission output signal at said third port of said first routing device resultant from said third divided transmission signal;

said second routing device having said second divided transmission signal applied to said first port of said second routing device and simultaneously producing:

a second divided transmission output signal at said second port of said second routing device; and

a second transmission leakage signal at said third port of said second routing device,

each resultant from said second divided transmission signal;

said second routing device also having a fourth divided transmission signal, when present, applied to said second port of said second routing device and producing, simultaneously with said second divided transmission output signal and said second transmission leakage signal, a fourth divided transmission output signal at said third port of said second routing device resultant from said fourth divided transmission signal;

a first modulator disposed to receive said first divided transmission signal, modulate said first divided transmission signal, and apply said first divided transmission signal, after modulation thereof, to said first port of said first routing device;

a second modulator disposed to receive said second divided transmission signal, modulate said second divided transmission signal, and apply said second divided transmission signal, after modulation thereof, to said first port of said second routing device

a signal divider/combiner having:

first and second divider/combiner ports for receiving said first and second divided transmission output signals and a configuration for combining these signals at levels within a second relative amplitude range and with a second relative phase shift therebetween to output said portion of said first transmission signal to said common port; and

said configuration being such that said second transmission signal, when present and received at said common port, said second transmission signal is divided into said third and fourth divided transmission signals having amplitudes within said second relative amplitude range and with said second relative phase shift therebetween; and

a signal combiner having first and second combiner inputs for receiving said first and second transmission leakage signals and, when present, for receiving said third and fourth divided transmission output signals, said signal combiner including said transmission signal output, and said signal combiner being configured to introduce a third relative phase shift into signals applied to at least one of said first and second combiner inputs and combine signals applied to said first and second combiner inputs at said transmission signal output at levels within a third amplitude range such that:

said first and second transmission leakage signals arrive at said transmission signal output at levels within an amplitude tolerance range and a total relative phase shift therebetween within a phase tolerance range situated about 180 degrees to effect a destructive combination resulting in at least partial cancellation of said first and second transmission leakage signals at said transmission signal output; and

said third and fourth divided transmission output signals, when present, arrive at said transmission signal output to effect a constructive combination of said third and fourth divided transmission output signals to output a portion of said second transmission signal at said transmission signal output.

45. An electromagnetic signal routing assembly for effecting two way duplex transmissions, comprising:

a transmission signal input for receiving first transmission signal;

a common port for outputting a portion of said first transmission signal from said transmission signal input and simultaneously receiving a second transmission signal;

a transmission signal output for outputting a portion of said second transmission signal;

a signal divider receiving said first transmission signal from said transmission signal input and dividing said first transmission signal into first and second divided transmission signals having amplitudes within a first amplitude range of each other and a first relative phase shift therebetween;

first and second routing devices each having at least first, second and third ports, said first and second routing devices being configured to simultaneously deliver a signal at said first port to said second port and another signal at said second port to said third port, wherein:

s21 is a transmission coefficient from said first port to said second port;

s32 is a transmission coefficient from said second port to said third;

s31 is a transmission coefficient from said first port to said third port;

said s21 is greater than said s31; and

said s32 is greater than said s31;

said first and second routing devices each be a duplexing filter;

said first routing device having said first divided transmission signal applied to said first port of said first routing device and simultaneously producing:

a first divided transmission output signal at said second port of said first routing device; and

a first transmission leakage signal at said third port of said first routing device,

each resultant from said first divided transmission signal;

said first routing device also having a third divided transmission signal, when present, applied to said second port of said first routing device and producing, simultaneously with said first divided transmission output signal and said first transmission leakage signal, a third divided transmission output signal at said third port of said first routing device resultant from said third divided transmission signal;

said second routing device having said second divided transmission signal applied to said first port of said second routing device and simultaneously producing:

a second divided transmission output signal at said second port of said second routing device; and

a second transmission leakage signal at said third port of said second routing device,

each resultant from said second divided transmission signal;

said second routing device also having a fourth divided transmission signal, when present, applied to said second port of said second routing device and producing, simultaneously with said second divided transmission output signal and said second transmission leakage signal, a fourth divided transmission output signal at said third port of said second routing device resultant from said fourth divided transmission signal;

a signal divider/combiner having:

first and second divider/combiner ports for receiving said first and second divided transmission output signals and a configuration for combining these signals at levels within a second relative amplitude range and with a second relative phase shift therebetween to output said portion of said first transmission signal to said common port; and

said configuration being such that said second transmission signal, when present and received at said common port, said second transmission signal is divided into said third and fourth divided transmission signals having amplitudes within said second relative amplitude range and with said second relative phase shift therebetween; and

a signal combiner having first and second combiner inputs for receiving said first and second transmission leakage signals and, when present, for receiving said third and

fourth divided transmission output signals, said signal combiner including said transmission signal output, and said signal combiner being configured to introduce a third relative phase shift into signals applied to at least one of said first and second combiner inputs and combine signals applied to said first and second combiner inputs at said transmission signal output at levels within a third amplitude range such that:

said first and second transmission leakage signals arrive at said transmission signal output at levels within an amplitude tolerance range and a total relative phase shift therebetween within a phase tolerance range situated about 180 degrees to effect a destructive combination resulting in at least partial cancellation of said first and second transmission leakage signals at said transmission signal output; and

said third and fourth divided transmission output signals, when present, arrive at said transmission signal output to effect a constructive combination of said third and fourth divided transmission output signals to output a portion of said second transmission signal at said transmission signal output.

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